Management of Natural and Environmental Resources for Sustainable Agricultural Development

Proceedings of a Workshop

February 13-16, 2006
Portland, Oregon
Management of Natural and Environmental Resources
for Sustainable Agricultural Development

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Editors
Robert Stefanski and Philip Pasteris

Sponsors
United States Department of Agriculture
Office of Chief Economist
World Agricultural Outlook Board
Natural Resources Conservation Service
Washington, D.C. 20250, USA

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Agricultural Meteorology Division
7bis, Avenue de la Paix
1211 Geneva 2, Switzerland

Series
AGM-10
WMO/ TD NO. 1428
NRCS-2008
WAOB-2008

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Washington, D.C. 20250 November 2008
Proper citation is requested. Citation:


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Foreword

Over the past two decades, there has been an increasing awareness of the potential damages that climate change, air and water pollution and inadequate natural resources management could induce upon human health, natural ecosystems and the economy. To address these concerns, considerable emphasis has been placed on sustainable development by many countries and international organizations. Accordingly, sustainable agricultural development has become a major issue of the 21st century.

Agriculture is today a key industry worldwide, since it is estimated that one out of nearly every three people is engaged in farming and agriculture, which provide practically all of the cereals, vegetables, meat, fish and forestry products that we depend upon. Consequently, farmers must make a most efficient use of all natural resources, in particular of soil, water and air, in generating these vital products.

With the accelerating population growth, diminishing arable land surface - especially in developing countries - , declining non-renewable energy supplies and an increasing awareness of potential environmental degradation, there is now much greater demand for sustainable management in the agricultural sectors of the world’s economies. Although food production in the developing world is expected to increase at a faster rate than in developed countries, cereal production will not be able to keep pace with demand. Cereal imports by developing countries are therefore expected to double in order to bridge the gap between food production and demand. Irrigated areas are also projected to grow at a slower rate during the next few decades than in the previous ones, and soil degradation is an escalating problem, especially in the developing world. The concept of sustainable agriculture therefore now encompasses ecological, economic and social issues for which weather and climate are key factors.

In particular, agricultural production is highly dependent upon weather, climate, and water availability, and sustainable agricultural development needs to incorporate weather and climate information in order to be most effective. Some examples of this fact include the use of climate information to select the most appropriate crops for a given region, thus contributing to sustainability; use of long-term climate information to ensure water availability for agricultural and other users of water management projects; use of climate information to assess the risk of land degradation as a possible consequence of certain land management practices; use of climate forecasts to determine the optimal distribution of crops to be grown and rangeland management practices to be implemented over the next growing season; and use of weather and climate forecasts to estimate fire risks in woodland management.

Weather and climate information can also be used to advantage in assessing the risk of agricultural and land practices that might somehow impact upon the environment. Recent studies have shown that runoff of agricultural fertilizers can be transported by rivers over thousands of kilometers and produce considerable impacts on marine ecosystems. In addition, weather and climate information is critical for real-time monitoring and long-term risk assessment of natural disasters, such as droughts, floods, grassland and forest fires, severe weather and tropical cyclones, which can induce very strong impacts on natural and environmental resources.
At the same time, it should be stressed that weather and climate information must be disseminated in an appropriate format and language to be easily understood by the various concerned sectors: farmers, forest and water resources managers, decision-makers and the general public.

The thirteenth session of the WMO Commission for Agricultural Meteorology (CAgM-XIII), which met in Slovenia during October 2002, considered the need to provide improved agrometeorological services to the agriculture, rangeland, forestry and fishery sectors, especially with respect to the sustainable management of natural resources, and therefore established an Expert Team on Management of Natural and Environmental Resources for Sustainable Agricultural Development.

WMO and the United States Department of Agriculture’s (USDA) Natural Resources Conservation Service (NRCS) subsequently organized a Workshop on Management of Natural and Environmental Resources for Sustainable Agricultural Development, which was held from 13 to 16 February 2006 at the NRCS’ National Water and Climate Center in Portland (USA). The workshop brought together experts of the CAgM Expert Team on Management of Natural and Environmental Resources for Sustainable Agricultural Development with those of the USDA NRCS, as well as from other U.S. government institutions. Twenty-five participants from 9 countries participated in the workshop.

I am pleased to note that 15 papers were presented at the workshop, focusing on various key aspects of natural and environmental resources management for sustainable agricultural development. I therefore wish to thank the USDA for its active collaboration in bringing out the workshop proceedings. I am confident that these articles and the recommendations developed during the workshop discussions, which are published in this volume, will serve as a vital source of information for the National Meteorological and Hydrological Services (NMHSs) of WMO’s 188 Members and for all agricultural and environmental agencies responsible for providing agrometeorological information and for supporting sustainable natural resources management in agricultural production.

(\[Signature\])
Secretary-General
World Meteorological Organization
Welcome Remarks by Raymond Motha

On behalf of the Commission for Agricultural Meteorology, welcome to this WMO Workshop on Management of Natural and Environmental Resources for Sustainable Agricultural Development. CAgM expresses its appreciation to the Natural Resources Conservation Service for co-sponsoring this workshop in Portland, the City of Roses. I want to acknowledge Jon Werner, Director, National Water and Climate Center, Bob Graham, Oregon State Conservationist, and Bruce Newton, Director, National Technical Support Center, for hosting this workshop. I also want to thank Phil Pasteris, Leader, Water & Climate Services, National Water and Climate Center, for coordinating the logistical arrangements for the meeting and for organizing the local programme.

As many of you know, the Pacific Northwest has a tremendous wealth of natural resources. Spectacular forests, expansive rangelands, and plentiful salmon are some of the many resources found in this region. Agriculture is also highly diversified and important in the Pacific Northwest. Winter wheat, potatoes, and apples are major crops grown in the region. The Northwest depends on winter precipitation, and especially snow, for its water supplies. In the western U.S., water supplies are limited but demands for water are increasing as urban population centers rapidly expand. Thus, this region is challenged with the complex issues of managing natural and environmental resources for sustainable agricultural development in a rapidly changing world.

In 1990, the U.S. Congress specifically addressed sustainable agriculture in the U.S. Farm Bill. Under this Public Law (101-624, Title XVI, Subtitle A, Section 1603), “the term sustainable agriculture means an integrated system of plant and animal production practices having a site-specific application that will, over the long term:

- satisfy human food and fiber needs;
- enhance environmental quality and the natural resource base upon which the agricultural economy depends;
- make the most efficient use of nonrenewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls;
- sustain the economic viability of farm operations; and,
- enhance the quality of life for farmers and society as a whole.

In the USDA/NRCS General Manual No. 180, Part 407, sustainable agriculture is defined as “a way of practicing agriculture, which seeks to optimize skills and technology to achieve long-term stability of the agricultural enterprise, while ensuring environmental protection, and consumer safety. It is achieved through management strategies that help the producer select hybrids and varieties, soil conserving cultural practices, soil fertility programs, and pest management programs. Sound resource conservation is an integral part of the means to achieve sustainable agriculture.”
Moreover, sustainable agriculture does not refer to a prescribed set of practices. Instead, it challenges producers to think about long-term implications of practices and broad interactions and dynamics of agricultural systems. This is important to local and regional agricultural systems. A systems perspective is essential to understanding sustainability, encompassing the individual farm to the local ecosystem to the communities affected by the farming system. A key goal is also to understand agriculture from an ecological perspective. Sustainable agriculture is also thought of in terms of its adaptability and flexibility over time to respond to the demands on natural resources and its ability to protect the soil, water, and environmental resources. Finally, a systems approach also implies interdisciplinary resources.

This leads me to focus briefly on why we are here. Weather and climate are major factors affecting agricultural production in both developed and developing countries. Weather extremes have caused significant agricultural losses, as well as loss of life and property, in many areas around the world. Tropical cyclones striking coastal regions have inflicted immense flood and wind damage, especially to lowland agricultural areas, but also some urban areas as well; droughts plaguing major crop and livestock areas have caused serious land degradation and desertification problems; desiccating winds fueling widespread forest fires have led to major ecological and erosion concerns; and anomalous winter snowfall in mountainous regions has major consequences on summer agricultural productivity, forest fire potential, streamflow conditions, and urban water supplies. These natural disasters and extreme events can lead to crop failure, food insecurity, loss of life and property, and can negatively impact socio-economic development in the affected region.

However, measures can be undertaken to help cope with natural disasters. These include a greater awareness of the vulnerability associated with natural hazards, planning and preparedness measures to help reduce the impact of the natural disaster, and an emphasis toward risk management. A CAgM Expert Team focused on the impacts and mitigation of natural disasters and extreme events in agriculture. Their work resulted in both an ambitious pilot project and the publication of their work in a book by Springer. Natural disaster mitigation plans should be factored into strategies for managing natural and environmental resources for sustainable agricultural development. These strategies for managing natural and environmental resources for sustainable agriculture can be achieved only through effective partnerships of experts from all disciplines and with all affected sectors of society.

Agrometeorologists, climatologists, hydrologists, agronomists, foresters, conservationists, extension service personnel and economists must pool their resources to exchange ideas and to formulate recommendations for managing natural resources in this rapidly evolving world. This interdisciplinary effort is essential for sustaining agricultural development.

I want to thank all of you for coming to this meeting. Your presentations will bring a broad range of expertise, unique challenges, and potential strategies for discussion. I sincerely wish you much success with these discussions and with the outcome of this meeting.

Thank you.
Agrometeorological Criteria for Management

and

Conservation of Natural Resources
Management of Natural and Environmental Resources for Sustainable Agricultural Development: Regional Diversity and Change Over the Pacific Northwest (Maritime, Rangeland, Riparian, Desert, and Forest)

Jan Curtis, Raymond Motha, Philip Pasteris
Natural Resources Conservation Service, Portland, Oregon; Office of the Chief Economist, Washington, D.C.; Principal Technologist, Global Water Resources, Portland, Oregon, USA

Abstract

Between 2000 and 2030, the population of the Pacific Northwest is expected to increase between 41 percent and 52 percent. With the possible additional stress placed on its water supply due to continued regional warming, the demand for water is expected to outpace the supply. Ecosystems will undoubtedly change and adapt but our ability to maintain or improve our quality of life will become increasingly problematic. Technology has kept up with changing demographics and changing climate since the Dust Bowl era. Agricultural yields continue to increase through better soil management, irrigation methods, genetic engineering, and environmental protection measures. By using new decision tools such as geographic information system (GIS), farmers, ranchers, municipalities, industry, and government now have the capability to maximize their access to renewable and limited natural resources. For example, the future success for rangeland management might very well depend on new hydro-meteorological networks (e.g., National Integrated Drought Information System) and new data (modeled) driven products.

Introduction

When the Clean Water Act (1977, 1990), Clean Air Act (1970, 1977), National Environmental Policy Act (NEPA, 1969), and the Endangered Species Act (ESA, 1973) (U.S. EPA, 2005) were introduced and subsequently amended by U.S. Congress, the national priority to provide citizens and wildlife with the healthiest environment possible had important implications and ramifications for each state. Besides mandates to better monitor all pollutants, states were directed to conform to new pollution standards as established and enforced by the Environmental Protection Agency (EPA).

Since then, many states have expressed dissatisfaction with the EPA on several counts. The first is that the federal government limits the amount of funding it provides to states to meet these requirements (unfunded mandates), and secondly, the pollution limits apply equally to all states; although each state has unique attributes such as population size, topography, types and amounts of industry, differing agricultural practices, and climate, just to name a few.

As the quality of life in the United States has improved due to technological advances in recent years, new markets have emerged. For example the leisure industry has witnessed an upturn in travel, recreation, and fitness activities. This in turn has helped promote healthier life styles as
noted by a move to organic foods, environmental awareness and protection, and planned urban development. Conservation can now be thought of as a commodity (new paradigm). Gathering sociological forces are focusing attention at maximizing limited resources through public education, charitable contributions, and volunteerism. The scientific community has an important role to meet these urgent needs and changing requirements. However, to understand how to accomplish this support in an environment of conflicting and competing interests, we need to trace past and recent trends in order to best estimate future stakeholders’ demands and expectations.

From 1965 to 1981, Presidential Executive Order 11331 authorized the establishment of the Pacific Northwest River Basins Commission. During this period, the Commission produced several reports that served as a comprehensive framework study of water and related lands. The value of this effort was not only to document and catalog all natural resources at the basin and sub-basin level, but to project how these resources would be used with future growth in population and economic development. In their 1972 report, they concluded that the population of the Seattle-Tacoma and Portland-Vancouver metropolitan areas would increase from 6.4 million in 1970 to 15.4 million by the year 2020 (Pacific Northwest River Basins Commission 1972). Total employment was expected to increase from 2.4 million in 1968 to 5.7 million in 2020. Municipal and industrial water requirements were expected to increase about 3 times, electric energy requirements over 10 times, recreation water demands over five times, and flood damage over four times by the year 2020 without additional zoning, control, and protection.

Although that 50 year forecast has yet to be completed and verified, increases in population due to increased immigration and longer life span were probably not in this Commission’s arsenal of model projections. Additionally, the public’s attitude concerning the environment and conservation has certainly gained momentum more quickly than expected with today’s information highway (such as, the Internet and satellite television). Finally, climate change and its impact to the environment was certainly a factor not considered. For example, the 1970s was a decade in which global cooling was popularized by the April 28, 1975, *Newsweek* magazine article (Gwynne, 1975) and other sources (Wikipedia, 2008). The focus was to emphasize that “a drop of half a degree [Fahrenheit] in average ground temperatures in the Northern Hemisphere between 1945 and 1968” had occurred.

With increasing evidence of global warming (Frederick and Gleick, 1999), the relatively arid and semiarid western United States is vulnerable to modest changes in precipitation, resulting in proportionally large impacts on water supplies both in terms of quantity and quality. In mountainous watersheds, higher temperatures will increase the ratio of rain to snow, accelerate the rate of spring snowmelt, and shorten the overall snowfall season; leading to more rapid, earlier, and greater spring runoff. While the scientific community is beginning to have a better understanding of atmospheric phenomena such as El Niño, more research is required. However, because the temperature projections of climate models are less speculative than the projections of precipitation (e.g., increasing CO₂ correlates well with increasing surface temperatures), temperature-induced shifts in the relative amounts of rain and snow and in the timing of snowmelt in mountainous areas should be considered by resource managers in any coping strategies or scenarios.
The U.S. Department of Interior (2005) has projected potential water supply crises by 2025. The Pacific Northwest is expected to experience moderate water supply conflicts although conditions may be more extreme due to Endangered Species Act issues along the Columbia River due to various species of salmon and steelhead and a shorter mountain snow accumulation season. Other areas of the Rockies and Southwest are not expected to fair as well.

The boundary of the Pacific Northwest is defined differently depending on what agency is responsible. For example, at lower elevations, the U.S. Bureau of Land Management lands are confined to part of Montana, southern Idaho, eastern Oregon, and nearly half of Wyoming. At higher altitudes, the U.S. Forest Service has domain over several National Forests (Cascades, Coast Mountains, most of western and northern Idaho, and the Rockies in Montana). From an eco-regions standpoint (Bailey, 2007), the Pacific Northwest boundary is defined by using physical, biological, and social considerations; and is broken into Maritime, some Mediterranean, and Temperate regimes. For more on the U.S. eco-regions, see the U.S. Forest Service ecosystems Web site at: http://www.fs.fed.us/rm/analytics/publications/ecoregionsindex.html.

Generally, the Pacific Northwest is quite diverse as noted by the U.S. Department of Agriculture’s (USDA’s) plant hardiness zones that range with minimum annual temperature from -40 degrees C over the highest peaks and deeper valleys of the Rockies to 0 degree C along the immediate Pacific coast (USDA, 2003). However, for the purpose of this paper (Figure 1), this region is defined as the drainage of the Columbia and Snake Rivers and encompasses all of Washington, most of Oregon and Idaho, smaller portions of northwest Montana and Wyoming, and northern Nevada (drainage of 70 million hectares).

Figure 1: The boundaries of the Pacific Northwest in the United States.
During the last two U.S. national census’ in 1990 and 2000, the percentage change in resident population for Washington, Oregon, and Idaho increased by 21.1 percent, 20.4 percent, and 28.5 percent, respectively (Perry and Mackun, 2001). This translates to more than a one million increase in population for Washington, between half to one million for Oregon, and between 100,000 and 500,000 for Idaho. While these increases are impressive, they pale in comparison to the 40 percent and 66 percent increases for Arizona and Nevada, respectively. Table 1 shows the population growth for select states across the West for the period 2000-2030.

Table 1: Expected population gains for selected western states from 2000 to 2030
(U.S. Census Bureau, 2005).

<table>
<thead>
<tr>
<th>State</th>
<th>Pop Gain</th>
<th>Percent Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nevada</td>
<td>2,283,845</td>
<td>114.3</td>
</tr>
<tr>
<td>Arizona</td>
<td>5,581,765</td>
<td>108.8</td>
</tr>
<tr>
<td>Utah</td>
<td>1,252,198</td>
<td>56.1</td>
</tr>
<tr>
<td>California</td>
<td>12,573,213</td>
<td>37.1</td>
</tr>
<tr>
<td>Idaho</td>
<td>675,671</td>
<td>52.2</td>
</tr>
<tr>
<td>Washington</td>
<td>2,730,680</td>
<td>46.3</td>
</tr>
<tr>
<td>Oregon</td>
<td>1,412,519</td>
<td>41.3</td>
</tr>
</tbody>
</table>

These increases are significant since already stressed water supplies over the West will become increasingly dire during the next 25 years. The doctrine of priority water rights (i.e., first in is first served), a long held practice in the West, may become challenged as urban centers continue to grow. This in turn would greatly impact agriculture in the West.

Climate and Climate Change

The Earth’s climate has undergone measurable change since the Precambrian Era (i.e., past 600 million years). During this period, there have been approximately four episodes in which the Earth has been exceptionally cold. Today, in spite of some global warming (~1 degree C during the past century), the planet is as cold as it gets in terms of the geological record. Of course, a half billion years ago the earth landmass looked quite a bit different than today while CO₂ was enhanced perhaps more than 10 times than its current value due to active volcanism. However, the climate system is a highly complex non-linear open system in which we do not fully understand the countless interactions that take place temporally and spatially.

It is known from proxy data of tree rings over Wyoming that during the past 700 years, droughts have existed, sometimes lasting for multiple decades. While droughts have been considered to be severe in the early 1900s, 1930s, 1950s, and the early 21st Century, they are considered to be mild when compared to the mega droughts of the 13th and 17th centuries. Certainly, the most recent drought over the West has affected more people than all the prior documented droughts. However, without today’s technology, the Native Americans of the Southwest had no chance to survive during extended dry spells one-half millennia ago.

Recent national climate trends show that much of the Southeastern United States has been cooling by a few degrees during the past three decades while the West, especially the Southwest is warming. Part of this cooling in the Southeast is explained by increasing cloudiness and
warming in the Southwest by the urban heat island effect and desert irrigation. Increased water vapor (also a greenhouse gas) keeps nighttime temperatures higher. Precipitation on the other hand is generally increasing across the United States. The greatest increases are in the Gulf Coast due perhaps to hurricane frequency. The General Circulation Model (GCM) predicts that with global warming, precipitation should increase. While this appears to be happening over the north central and western third of the country, it is far from happening everywhere.

As the CO₂ level rises, remote satellite imagery reveals that independent of temperature, the mid latitudes are showing an explosion of vegetation (greening). This would be expected since CO₂ is the essential source for plant fertilization.

The Pacific Northwest experiences average annual precipitation from less than 25 cm over portions of eastern Washington and Oregon and southern Idaho to totals in excess of 450 cm over the higher elevations of the Cascades and Coastal Mountains. There is, however, large inter-annual variation in part due to the strengthening and location of the El Niño Southern Oscillation (ENSO). Perhaps more important than precipitation amounts are the timing of such events. Up to 89 percent of precipitation falls over the western mountains between the 6-month period from October through March (50 percent would be expected with a normal distribution). Thus the importance of mountain snow pack is vital for water supplies. If the snow accumulation season is shortened, there is less opportunity for spring runoff and capture. The reverse occurs over the Great Plains when spring moisture exceeds normal expectations by nearly double. The timing of these precipitation events is critical for dry land farming/ranching. Studies show that native cool grass growth used for livestock foraging is independent of precipitation that falls during other seasons.

The Pacific Northwest contributes to 15 percent of the U.S. production of winter wheat. However, the success for a surplus harvest depends on critical temperature thresholds in the fall and spring. If the U.S. climate is expected to change so that it experiences larger temperature and precipitation swings from the long-term average, wheat and other crops not only in the Pacific Northwest will become more vulnerable.

Why are the lower elevations of the intermountain West so arid? This is clearly illustrated by looking at how precipitation is a function of elevation over Wyoming (Curtis and Grimes, 2004a). With extreme low surface relative humidity, strong winds, and high temperatures, evapotranspiration (ET) values are extremely high due to evaporation exceeding precipitation by up to four times. While most land is below 2,286 meters of elevation, less precipitation reaches the ground than at higher elevations. ET is lower and precipitation exceeds evaporation above 2,286 meters. Mountains therefore become our natural reservoirs for water storage and release.

**Changing Agriculture and Conservation Practices**

The agriculture industry is in constant flux as irrigated and dry land farming contends with urban growth and a diminishing water supply. Smaller farms (i.e., less than 500 acres and annual sales of less than U.S. $10,000) are being sold to larger corporate farming enterprises or to land developers. Any improved efficiency in these corporate farms could be lost to the expansion of the suburbs into more rural areas. The landscape is also changing due to the current western
drought which has caused the historical lowest levels of water storage and capacity on the Colorado River. Additionally, restrictions imposed by the Endangered Species Act on activities along the Columbia River has forced many a land stakeholder to rethink about their livelihoods or to move on.

From 1997 to 2002, large regions east of the Cascades have seen a marked decrease in farm acreage. Irrigated lands have also decreased especially in Idaho and in western Montana and Wyoming. Certainly, the severity of the current western drought in 2002 was a major contributing factor. While some crops, such as alfalfa showed some increases in yield, potatoes and all wheat crops showed a decline. A mixed trend was also seen in the cattle industry. Beef cows declined while milk cows were on the increase. Whether these trends will change is highly problematic. However, by better understanding successful farming techniques and emerging technologies, these stewards of the land will have a fighting chance at helping to feed the nation and the world. The following are some examples of successful farming techniques.

Understanding plant moisture requirements is a critical component to water resource management. Field studies show that about 40 percent of the total moisture intake by plants is extracted by the plant’s roots from zero to 15 centimeter (cm) depths; 30 percent from 15 to 30 cm; 20 percent from 30 to 45 cm; and 10 percent from 45 to 60 cm (Curtis and Grimes, 2004b). Each soil type has an inherent available water holding capacity which can vary from 2.5 cm per hectare for loamy sand to 6.2 cm for silty clay loam. Consequently, a 60-cm root zone will typically have an irrigation water requirement that can vary between 3.75 cm (153,300 liters per hectare) for a coarsely textured soil to 60 cm (255,515 liters per hectare) for a finely-textured soil. Most flood irrigation systems are between 45 to 70 percent efficient, therefore 7.5 cm (306,618 liters per hectare) is a recommended application.

Local experience recommends that irrigation should be applied when 30 to 50 percent of the available water is depleted in the zero to 30-cm root zone and when about 15 to 30 percent is depleted in the 30- to 60-cm root zone. It takes about 48 hours for the surface moisture to recharge the soil to a 60-cm depth for most soils. As a general guideline, a fully mature tree at peak water consumption can remove 0.5 to 0.75 cm of moisture per acre per day. This translates to irrigating between eight and 10 days if no precipitation occurs during this interval. Of course solar radiation, wind, humidity, temperature, precipitation, crop variety, soil drainage, and water quality are important factors for successful irrigation.

In 1997, thousands of square kilometers (km) of land were eroded by wind on croplands along the Snake River in southern Idaho and over the Columbia River in Washington and Oregon. While weather can contribute to top soil losses as witnessed during the Dust Bowl Era, erosion can be reduced through the employment of some basic techniques such as the use of snow fences, drip irrigation systems, and riparian restoration. There are numerous other examples as addressed on the Natural Resources Conservation Services (NRCS) Climate Data and Conservation Practices Web site (NRCS, 1998).

In the higher altitude valleys of the Pacific Northwest, a remarkable fact about blowing snow is that after being transported along the ground for 8 km, it has essentially lost all its moisture through a process called sublimation. In order to prevent any sublimation or evaporation of
snow or melted snow, snow fences are employed not only to prevent snow drifts from blocking roads but to collect these drifts for later melt into holding ponds for livestock. Snow fences come in two forms and each has inherent pluses and minuses:

The conventional one-meter high slatted fence and the Wyoming Design board snow fence that stands 2.5 to 4.2 m high are the most popular structural fence designs. Their advantages include that they can be:

- Erected and put into use very quickly;
- Used at sites where vegetation is not practical.

Their disadvantages include:

- High establishment and annual maintenance costs;
- Life span of materials is 20 years.

The other form is the Living Snow Fence (vegetation) which has the following advantages:

- Much less expensive than structural fences (i.e., nearly seven times less);
- Life span is 50 years;
- Designed for wildlife habitat, livestock protection;
- Used as visual screens and helps to reduce soil erosion.

Their disadvantages include:

- Long-time lag before vegetation starts to trap snow;
- Barrier density may vary as vegetation grows at different rates;
- Vegetation is susceptible to damage from insects, disease, etc.

Another technique that is gaining wide acceptance is the use of drip irrigation. Studies have shown that it uses 30 to 50 percent less water than conventional flood irrigation or sprinklers (Hutmacher, et al., 2001; Jifon, et al., 2005; Henggeler, 2004). This also helps to prevent soil erosion and nutrient runoff and weeds are discouraged to spread. Controlling moisture suppresses fungal diseases. For example, in Wyoming, 80 percent of water is used by agriculture and 90 percent of that is for flood irrigation. Clearly, a conversion to a drip irrigation system is essential in order to get an upper hand on dwindling water supplies.

Riparian restoration using vegetation is proving more effective than using structures to control stream and river flow. Vegetation heals itself and adjusts to changes in flow and landform. Besides enhancing wild life habitats, these restorations help to reduce erosion.

Field studies have indicated that climatic averages may no longer support dry land farming yield forecasts. In a 4-year period, increased variability in rainfall resulted in the same long-term average amounts, but impacted the ecosystem in two ways. First, the native grassland biomass was reduced by fewer precipitation events with greater rainfall amounts per event as compared to more events with lesser rainfall amounts per event. Second, plant species diversity increased.
Thus, these findings suggest that the prairie can exhibit rapid changes to its biodiversity even though the climate rainfall totals do not show long-term trends. In another study, increased spring minimum temperature was correlated with decreased net primary production by the dominant C4 grass (grazing forage) and with increased abundance and production by exotic and native C3 forbs. Thus this scenario may make a region more vulnerable (less tolerant) to drought and grazing. Finally, native biomass yields were shown to be moderately correlated to precipitation events from late March to mid May in Wyoming.

**Land Use Changes**

LANDSAT and other remote satellite platforms have been around long enough to clearly reveal that land is changing. In the urban setting of Puget Sound, Seattle’s expansion into the surrounding rural areas is quite apparent from 1973 to 2000. In a rural setting, significant forest clear cutting over the northern California Coastal Range is striking from 1986 to 2000.

In the 1972 report by the Pacific Northwest River Basins Commission described earlier, it was projected that cropland will increase to over 137,000 hectares by 2020 but that forest land and rangeland will decrease by 277,000 and 374,000 hectares, respectively (Table 2).

<table>
<thead>
<tr>
<th>Type</th>
<th>1966</th>
<th>1980</th>
<th>2000</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cropland</td>
<td>3,410</td>
<td>3,532</td>
<td>3,509</td>
<td>3,547</td>
</tr>
<tr>
<td>Forest Land</td>
<td>14,070</td>
<td>14,000</td>
<td>13,898</td>
<td>13,793</td>
</tr>
<tr>
<td>Rangeland</td>
<td>9,628</td>
<td>9,393</td>
<td>9,357</td>
<td>9,254</td>
</tr>
<tr>
<td>Other Land</td>
<td>1,364</td>
<td>1,468</td>
<td>1,591</td>
<td>1,719</td>
</tr>
<tr>
<td>Total Land</td>
<td>28,472</td>
<td>28,392</td>
<td>28,354</td>
<td>28,314</td>
</tr>
<tr>
<td>Water Areas</td>
<td>313</td>
<td>392</td>
<td>431</td>
<td>471</td>
</tr>
</tbody>
</table>

Whatever the actual current numbers are regarding land use changes, impacts to our natural resources are occurring.

Current land use, as measured by building per square km, shows the densest population between the Coastal Mountains and the Cascades. Projected land use changes during the next 50 to 100 years may be subtle (Johnson, et al., 2007 and Kline, et al., 2003); however, encroachment into our National Forests and watersheds will have serious implications on balancing requirements between water supply and demand.
Hydro-meteorological Networks

The best defense for protecting our environment is our ability to monitor hydrological and meteorological elements in real time. The Pacific Northwest and the western half of the United States still lack a high-density monitoring capability. While there are several networks in use (e.g., AgriMet, SNOTEL, SCAN, RAWS, COOP, radar, USGS, rawinsondes, etc.), interoperability with respect to communication is still lacking. Soil moisture sensors, at the heart of modeling runoff, are slowly improving but there are budgetary issues to overcome. However, with the implementation of the National Integrated Drought Information System (NIDIS) (Western Governors Association, 2004), this framework architecture will maximize all environmental sensors that are available.

The New Paradigm

Traditional climate data includes average temperatures, total precipitation, and extremes, usually based on a 30-year period of record. These “Normals” are updated at the start of each decade and these values change with each update. While these data are beneficial for planning activities, average weather and climate conditions are seldom experienced, especially during shorter time intervals (i.e., hourly, daily, or even monthly). With computers, climate data can now be easily compiled to show statistical probabilities for a given weather element and as the period of observations increase, important trends can have important implications as discussed below.

In Wyoming, forage production of non-irrigated grasslands is strongly tied to precipitation events at a specific time of year. For example, at Saratoga, Wyoming, biomass yields are directly correlated to precipitation that falls during the period of April 12-19 and is independent of precipitation that falls at other times of year. This simple relationship provides a reliable management tool for herd distribution since it takes up to 16 hectares to feed one cow in this arid regime. Timing is everything.

In another study over the Great Plains, the distribution of precipitation over time has an important impact on grazing and biodiversity (Knapp, et al., 2002). Although during the same period a similar amount of precipitation had occurred, when there were more events of lesser amounts per event, forage grasses were decreased, and more plant species developed. In this case, frequency and intensity of precipitation proved to be more important than precipitation amounts.

Finally, a study has revealed that as night temperatures increased over the Great Plains, forage grasses decreased, became less tolerant to drought, and resulted in poorer grazing opportunities (Alward, 1999). Climate trends suggest that the ecology of a region may be more or less adaptive to small changes with certain climate parameters. Thus, when using climate data, there is a need to start thinking about how to use it differently. Averages, totals, and extremes may not provide enough information to describe ones environment.

Exciting work is underway that establishes a methodology for the systematic quality control of SNOw TELelementry (SNOTEL) using a probabilistic-spatial approach. By using Parameter-
elevation Regressions on Independent Slope Model (PRISM) spatial gaps in climate data can be accurately estimated with surrounding existing weather stations (Figure 2; Daly, et al., 2002). A bibliography of the PRISM papers can be found at the following Web site: http://www.prism.oregonstate.edu/docs/index.phtml.

Figure 2: Example of one station’s temperature as compared to other neighboring stations (Daly, 2007).

Conclusion

The socioeconomic implications of both climate and non-climate impacts on water supply and demand will depend in large part on both the ability to adapt to change and on whether water managers and planners take action. With the uncertainties associated with increasing federal regulation of the environment, changing demographics and technologies, and budgetary realities, we need to re-examine infrastructure design assumptions, operating rules, and contingency planning under a wide range of climate conditions than has been traditionally performed. Maintaining options and building in flexibility are important for designing efficient water programs in the context of climate change. Additionally, future climate products need to incorporate all sensors and their associated networks, and these data must be customized for each stakeholder’s unique requirement.

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References


Abstract

There is a need for a national network that provides near real-time soil moisture and temperature data combined with other climate information for use in natural resource planning, drought assessment, water resource management, and resource inventory. In 1991, a 10-year pilot project was started to test the feasibility of such a network. Initially, 21 stations were established in the pilot project. Over the span of the project, an array of above ground and below ground sensors were tested along with a unique meteor burst communication system. This pilot led to the development of the Soil Climate Analysis Network (SCAN). The network now has 115 stations, of which most have been installed since 1999, located in 39 states. The stations are remotely located and collect hourly atmospheric and soil moisture and temperature data that is made available to the public via the Internet. Future plans for the network include locating new stations on benchmark soils, increasing the number of stations, making data summaries more user-friendly, and increasing data quality.

Introduction

The SCAN is a network of soil climate monitoring stations located across the United States. The network was first initiated in 1991 as a pilot project (USDA-NRCS, 2004). The goal of the project was to test the feasibility of establishing a national soil-climate monitoring program that meets the growing demands of the global climate change community, modelers, resource managers, soil scientists, ecologists, and others. Soil water status, soil temperature, and associated atmospheric measurements were identified as critical parameters for many applications such as continental-scale climate models, soil classification, and drought and flood assessments. In the first year, 21 soil moisture and temperature (SM/ST) stations were installed and, later, 9 stations were added in watersheds around the country in cooperation with USDA’s Agricultural Research Service (ARS). In 1999, SCAN was officially started with support and financial assistance from the USDA’s ARS and the USDA’s World Agricultural Outlook Board, Joint Agricultural Weather Facility. The network was designed to be a cooperative nationwide effort, with the Natural Resources Conservation Service (NRCS) as the leader. The main focus of SCAN was on agricultural areas of the United States.

The current network is comprised of 113 stations, which are located in 39 states (Figure 1). Under the proposed full implementation of SCAN, more than 1,000 new remote sites would be added (USDA-NRCS, 2004). This would be accomplished by (1) integrating information from existing soil-climate data networks and (2) establishing new data collection points through partnerships with Federal, state, local, and tribal entities. This design will support natural
resource assessments and conservation activities well into the 21st century; however, the full implementation of SCAN is dependant upon additional funding.

Figure 1. Location of soil climate analysis network stations.

Most other networks have been severely limited by the lack of quality for historic and real-time soil-climate information. Also, existing data from other networks are essentially inadequate for most purposes since they tend to be application specific, short-term, incomplete, or limited in area of coverage; often include nonstandard sensor arrays; and typically are difficult to obtain. SCAN has overcome many of those problems, ensuring standard sets of sensors and making the data available to users via the Internet in near real-time. Since the inception of the pilot project in 1991, significant knowledge and experience have been gained in the type of sensors used, maintenance, station network operation, quality control, product analysis, and dissemination of information to users. This experience has been used to build, operate, maintain, and develop products that our customers require in order to make sound resource management decisions. The objectives of this paper are to describe the current network and its future.

Soil Climate Analysis Network

Siting Criteria

The location of monitoring sites varied from place to place, depending on the objectives or purpose of the station. For example, in the eastern United States, 10 sites were established to test the communication range of the meteor burst master station. In the western United States, sites
were established to collect additional information to accurately characterize soil moisture and temperature regimes in drought susceptible soils.

The local NRCS state office staff provided valuable information required to implement SCAN in their state. It is envisioned that the NRCS State Resource Conservationist, State Soil Scientist, State Range Specialist, and other local field office staff will be involved in the ultimate selection of station locations. The local State Climatologist, Drought Coordinator, and other state and local government officials can provide key information on critical areas of the state that require monitoring. They can help guide the selection process to ensure that a site represents a predominate climate regime. The following criteria were established for the location of all sites:

1) First priority is given to federally managed land, second priority to state managed land, and third priority to private land. Ideally, stations should be located on federal, state, county, or university land. This will ensure long-term use of the land for monitoring purposes. When it is not possible to locate stations on this type of land, consideration should be given to locating the station on property of Soil and Water District landowners that are cooperators with NRCS.

2) Sites should be approved by a qualified Cultural Resources Specialist.

3) Sites should be accessible by vehicle, and fencing of the site should be allowed.

4) When selecting a suitable location, some consideration of station security must be included. Generally, stations should not be located near public roads and should be located away from public view.

5) Consideration should be given to co-location with Long-Term Ecological Research Sites or other long-term monitoring projects, such as Forest Service Remote Automated Weather Station sites and Agricultural Research Service (ARS) Agricultural Experiment Stations.

6) Consideration must be given to ensure that all Major Land Resource Areas are represented in a given climatic region.

7) Benchmark soils are given priority as sites, and the soil type should be of significant acreage in the area where the station is located. Using the NRCS Benchmark Soils list will ensure that this is accomplished.

8) Soils should be very deep (>60 in), well drained, and, preferably, medium textured.

9) The landscape position of the site should be typical for the soil map unit.

10) The station should represent an agricultural area. The management status should be stable; e.g., in grass vegetation. All stations should be located in nonirrigated areas.

11) Consideration should be given to the World Meteorological Organization’s requirements for weather station siting criteria (WMO, 1996). Using these requirements will ensure that proper distances are maintained from objects that could interfere with sensor performance.

For the stations involved in research, the siting requirements can be different depending on objectives. This may result in locating a station in an area that would fail one or more of the preceding criteria.
Soil Characterization

The soil at each SCAN site is fully characterized by documenting site properties, including vegetation, slope, aspect, and other important properties. A pit is opened with a backhoe, and the soil profile is described to a depth of 2 meters (when possible). Soil depth, texture, the content of rock fragments, structure, rupture resistance, color, and the quantity and size of roots are described for each horizon using standard soil description techniques (Schoeneberger, et al., 2002). Soil samples are collected from each horizon and sent to the National Soil Survey Laboratory in Lincoln, Nebraska, for standard characterization analyses. Standard properties measured include particle size separates (pipette method); bulk density (clod method); water content at 10, 33, and 1,500 kPa; cation-exchange capacity (CEC) (buffered ammonium acetate); total C; and pH (1:1 soil:water). The procedures for sampling and properties characterized are described in SSIR No. 1 (Soil Survey Staff, 1972). The current laboratory methods are described in SSIR No. 42, version 4.0 (Burt, 2004). Local NRCS soil scientists describe the soils and assist with the sampling.

Station Configuration

The standard SCAN station configuration has remained fairly consistent since 1999, with minor changes for station specific user requests. Dataloggers are 2MB units that are programmed to record sensor data every 20 minutes and to store data hourly. The data is then transferred to a radio and sent out to a master station. Table 1 lists the standard set of sensors that are included on all SCAN stations. Additional sensors are added to some SCAN stations to support local needs. For example, on seven stations in the north-central and eastern United States, snow pillows and depth sensors have been added to measure snow weight and thickness. These sensors are critical to assist with the prediction of surface water runoff and flood forecasting. Stations developed for specific research typically have the same standard suite of sensors with the addition of sensors used for specific investigations. Table 2 lists most of the additional sensors used on the research stations. Some or all of the sensors listed may be associated with a station.

Table 1. List of standard sensors used in the SCAN.

<table>
<thead>
<tr>
<th>Parameter Measured</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air temperature</td>
<td>Collected by a shielded thermistor</td>
</tr>
<tr>
<td>Relative humidity</td>
<td>Collected by a thin film capacitance-type sensor</td>
</tr>
<tr>
<td>Wind speed and direction</td>
<td>Collected by a propeller-type anemometer</td>
</tr>
<tr>
<td>Solar radiation</td>
<td>Collected by a pyranometer</td>
</tr>
<tr>
<td>Barometric pressure</td>
<td>Measured by a silicon capacitive pressure sensor</td>
</tr>
<tr>
<td>Soil moisture</td>
<td>Collected by a dielectric constant measuring device. Typical measurements are at 2, 4, 8, 20, and 40 inches where possible.</td>
</tr>
<tr>
<td>Soil temperature</td>
<td>Collected by an encapsulated thermistor. Typical measurements are at 2, 4, 8, 20, and 40 inches where possible.</td>
</tr>
</tbody>
</table>

The SCAN stations are designed to be located remotely. The entire station is powered by solar panels and batteries. Proper determination of station power requirements is critical to maintain
system performance and ensure good sensor data. The sensors chosen for SCAN require very little power, and solar panel and battery technologies have improved over the years. The larger, more efficient solar panels that have been developed are better at charging batteries.

Table 2. List of additional sensors used in research.

<table>
<thead>
<tr>
<th>Parameter Measured</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piezometer</td>
<td>Water level</td>
</tr>
<tr>
<td>Redox</td>
<td>Measurement of oxygen reduction potential</td>
</tr>
<tr>
<td>Soil temperature</td>
<td>Additional soil temperature measurements by different devices</td>
</tr>
<tr>
<td>Water quality</td>
<td>Water temperature, pH, turbidity, DOB, and conductivity</td>
</tr>
<tr>
<td>Surface soil temperature</td>
<td>Typically measured by an IR sensor</td>
</tr>
</tbody>
</table>

Good grounding is critical for the equipment to operate properly. The radio and antenna make up a ground-based system that requires a proper ground to maintain communications between the remote station and the master station. Over the years, several stations have gone down due to lightning damage. Improved grounding and static dissipaters have decreased downtime of these lightning prone stations.

The average cost for a standard SCAN station is about $18,000 for the sensors, radio, and datalogger. USDA’s NRCS estimates that a SCAN station and sensors are good for a minimum of 10 years.

Station Data Acquisition

The SCAN system utilizes meteor burst communication technology or Line-of-Sight (LOS), to remotely acquire station data. The communication system is connected to a datalogger. Meteor burst communication was developed by the military in the 1950s, but no effective system was implemented until NRCS and its contractors developed Snowpack Telemetry (SNOTEL) in 1975 (USDA-NRCS, 2003). Meteor burst communication uses the billions of sand-sized particles (1 gram or larger) that burn up in the 50- to 80-mile-high region of the atmosphere to relay radio signals back to the Earth (MeteorComm, 2004). This technique allows communication to take place between remote sites and a master station as far as 1,200 miles away. Upon entering the Earth’s atmosphere, the particles burn up and leave an ionized gas trail behind. This gas trail enables VHF radio signals in the 38MHz to 50MHz range to reflect, or reradiate, signals back to the Earth. These signals generate a communications footprint on Earth, and, if the remote sites located in the footprint hear the master station signal, they will transmit their data back to the master station. At the master station, the remote site data is checked for completeness. If the data is complete, an acknowledgment message is sent back to the remote site, along the same path, telling the remote site not to transmit again until new data are ready to be transmitted. All three transmissions take place in less than a tenth of a second.
A datalogger is connected to the meteor burst radio and is responsible for the collection and processing of the sensor data. Data are summarized and transferred hourly to the radio for transmission.

Meteor burst communication has proven to be extremely reliable for data acquisition purposes. The LOS system, which uses the same radio that is used for meteor burst telemetry, has improved over the years. Much of this improvement is the result of agency electronic maintenance technicians and managers becoming knowledgeable on how to optimize the performance of equipment at remote sites, maintain the master station, and improve upon the hardware and software used. On the average, more than 98 percent of all remote sites report data at midnight; the less than 2 percent failure rate is generally related to some electronic failure, not to a meteor burst communication failure.

**Station Maintenance**

As with any network, maintenance is a very critical component in maintaining data quality. From the beginning of the pilot project, station maintenance was a major concern. Some stations collected poor information and performed poorly because of the lack of maintenance. Currently, typical station maintenance for SCAN is scheduled to be performed annually. Typical maintenance includes sensor and datalogger calibration, repairs, upgrades, and preventative measures; e.g., replacing desiccant, checking enclosure seals, and removing vegetation. Inadequate funding and the limited number of personnel continue to restrict the adequate maintenance of all stations. During the past 2 years, new stations generally were installed in areas where local staff could help with station maintenance, under the direction of the USDA’s NRCS National Water and Climate Center (NWCC) staff. This arrangement has proven to be very effective and has ensured better performance at those stations. The NWCC staff and the National Soil Survey Center (NSSC) staff still perform the bulk of the station maintenance. Additional staff personnel are needed in order to ensure station reliability. While the NWCC and NSSC desire to maintain the stations annually, it is not possible with the current staffing levels.

**SCAN Data Access and Reliability**

SCAN data are available hourly from the USDA’s NRCS-NWCC homepage at http://www.wcc.nrcs.usda.gov/scan. Each remote station should respond with hourly data at the top of each hour. The time interval between when the station reports to when the data is posted on the Internet is typically 30 minutes. Once the data arrives at the NWCC, a computer performs an initial data quality check; this screening ensures that the sensor data are within reasonable, predefined limits. Additional automated data screening, which may include rate of change for air temperature and rate of change for precipitation, is envisioned in the future to assist with data quality.

Users can easily obtain SCAN data from the NWCC homepage. Specialized reports can be requested via e-mail by identifying the specific stations and the period of record. New reports will be developed to provide easier retrieval of station data in the future. Station metadata files, which provide sensor history, calibration, station pictures, and maintenance history, are currently being developed for each station, and they will be linked to the NWCC homepage.
The real-time data provided on the Internet are provisional and subject to change. The NWCC believes that the information is valuable but recommends that people be cautious when they use the data. The data is examined weekly and edited for obvious sensor problems. These edits are in the historical data files, which are also accessible via the Internet. Problems that require maintenance visits to a station are identified during the data examination, and the NWCC tries to schedule station visits based upon the identified problems.

Over the years the NWCC has supported several independent analyses on the SCAN data. In 2001, an initial determination of the quality of the soil moisture sensors (hydra probe) was undertaken. The hydra probe sensors are a capacitance type of device that provides volumetric soil water content, salinity, and soil temperature information (Stevens, 2006). In addition, the University of Idaho, USDA’s Agricultural Research Service, and the NWCC were successful in obtaining a U.S. National Oceanic and Atmospheric Administration (NOAA) grant to examine the soil moisture sensor (hydra-probe) data from the SCAN network. ARS provided an evaluation of the Vitel “hydra probe” to see how consistent the soil moisture sensors were and how they behaved in known soil water concentrations (Seyfried and Murdock, 2004). The results demonstrated the reliability of the hydra probe sensors. The hydra probes have been used in SCAN since 1995 and have provided reliable soil moisture information.

A Cooperative States Research proposal has recently been funded between Oregon State University, Alabama A&M University, and NWCC to begin the development of a tool that will integrate SCAN data with soils information and distribute soil moisture spatially. The development of the science to accomplish this task is critical to be able to provide “risk” information about soil moisture conditions nationally. The work has just begun and is envisioned to take at least 3 years to develop and test. If this work is successful and SCAN is fully implemented in the United States, it will be possible to identify potential drought areas and predict where future drought conditions could appear.

**Future of SCAN**

The SCAN network has grown over the years, and the popularity and usefulness have grown exponentially. The number of data downloads has risen dramatically. In fiscal year 2005, more than 1 million downloads took place. The number of requests for new stations has exceeded the NWCC ability to fund, install, and maintain the network. The main reasons for establishing the network were to assist agriculture with resource decisionmaking, to develop tools to look at crop production and the control of diseases and pests, and to mitigate drought affects by reducing the risk involved. Additional uses of this type of network and uses of the data continue to grow as well. The pipeline industry and fiber-optic cable companies are using the information to determine freeze depths and how far apart transmission buster stations can be located. The nationwide need for reliable, readily available soil moisture and soil temperature information has been demonstrated by the number of users obtaining SCAN data. A larger network with new stations and partnered stations would provide this type of national coverage. To date, half of the funding for SCAN has come from co-operators. These co-operators are excited about the future of the network.
The SCAN, when fully deployed, would consist of approximately 2,000 stations: 1,000 new stations and about 1,000 existing stations operated by other entities. The co-operator stations would be upgraded to meet SCAN standards in order to seamlessly provide a full spectrum of climate information to users. Proper siting of the new SCAN stations is critical to ensure representative spatial coverage for the agricultural regions of the United States. While the future of the network is still uncertain unless a more stable funding source is found, one thing is certain: SCAN has a vital role to play in integrating soil-climate monitoring. No other system that provides this kind of information exists in the United States.

References


Assessing the Impact of Natural Resource Management for Sustaining the Mountain Farming System in Nepal

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Nepal Agricultural Research Council, Khumaltar, Kathmandu, Nepal

Introduction

Agriculture as an art and science has the legacy of human civilization and is necessary for survival. During the course of civilization, other life supporting means such as clothing and shelter followed. Nepal’s economy has also been connected with agricultural development. Nepal’s share of agriculture commands nearly 39 percent of the Gross Domestic Products (GDP) employing over three-fourths of the active population. Agriculture in Nepal best survives on renewable resources — land, water, air — and those living on them and supporting agriculture. These resources are forest and pasture, livestock, biodiversity, nutrients, and foods and their ecosystems. They survive the interactive relationship in existence often in a symbiotic manner. The traditional agricultural system evolved when there was little or no intervention from the outside to sustain and support the human and animal activities. However, the present state of population growth and modernization gradually tilted towards the imbalance threatening the whole ecosystem. These resources at the same time are renewable and can be sustained if adequate management methods are used. Therefore, wise management of our resources has become the primary concern to sustain agricultural development. Figure 1 shows a typical existing flow of natural resources to sustain the farming system in the hills of Nepal.

Figure 1. A simple diagram of flow of resources in the hill farming system of Nepal (Pound, et al., 1990)
Degradation Process

The human drive for acquiring more and the resulting inequity among societies has been accelerated by the process of modernization and globalization. Our natural resources are fast approaching being exhausted primarily for three reasons:

- Traditional or indigenous management of natural resource management are not practiced or less practiced or neglected.
- Unchecked population growth is threatening natural resources and is leading to their degradation.
- Globalization further increased the process of mining of various resources.

Land Degradation

Land is vital to agriculture and is embodied as the mother of agriculture. Due to the fragile geological environment of the Himalayan system, the land degradation process is active. Anthropogenic activities have been the primary factor for increasing the degradation process. The rainfall behavior during the monsoon has also increased the process of land degradation due to various water-induced erosion processes. The forest ecosystem has been facing a constant threat from being converted into shrubs then to agricultural land and other purposes. During the last 30 years, the forest of Nepal has declined 13.8 percent — from about 42 percent in 1978/79 to 29 percent in 1994/95 — of the total land use (Table 1). The loss of forest was estimated to be 1.3 percent in the Terai and 2.3 percent in the hills annually. In 1985, estimated soil losses from different land categories could be 5 tons per hectare (t/ha) to 200 t/ha (UNEP, 2001) shown in Table 2. It was estimated that annual loss of 5 t/ha of soil would lose about 75 kilograms (kg) carbon, 3.8 kg nitrogen (N), 10 kg potassium (K) and 5 kg phosphorus (MOPE, 2001).

Similarly, the Ministry of Population and Environment (MOPE) estimates that there were about 10,000 ha of land under the process of desertification in parts of Nepal. The losses have not been reversed in a sustained way resulting in increased degradation, which might gradually be converted into marginal lands not suitable for farming.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Agriculture</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Cultivated</td>
<td>16.5</td>
<td>20.0</td>
<td>20.2</td>
<td>3.7</td>
</tr>
<tr>
<td>b. Non-cultivated</td>
<td>10.3</td>
<td>6.5</td>
<td>6.7</td>
<td>-3.5</td>
</tr>
<tr>
<td>Pasture</td>
<td>11.9</td>
<td>11.9</td>
<td>12.0</td>
<td>0.1</td>
</tr>
<tr>
<td>Forest</td>
<td>42.8</td>
<td>37.7</td>
<td>29.0</td>
<td>-13.8</td>
</tr>
<tr>
<td>Shrub</td>
<td></td>
<td>4.7</td>
<td>10.6</td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td>18.5</td>
<td>19.3</td>
<td>21.5</td>
<td>3.0</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Land use</th>
<th>Soil erosion rate (t/ha/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well managed forest land</td>
<td>5 – 10</td>
</tr>
<tr>
<td>Well managed paddy terraces</td>
<td>5 – 10</td>
</tr>
<tr>
<td>Well managed maize terraces</td>
<td>5 – 15</td>
</tr>
<tr>
<td>Poorly managed slopping terraces</td>
<td>20 – 100</td>
</tr>
<tr>
<td>Degraded range lands</td>
<td>40 – 200</td>
</tr>
</tbody>
</table>

Land degradation can also be explained in terms of nutrient exhaustion due to increased consumption by crops. The carrying capacity of the land to support agriculture has become more and more vulnerable. Joshy (1997) reported that every year 1.8 million tons of nutrients are taken up by crops and the nutrient replenishment by fertilizer amendments makes only 0.3 million tons (16 percent) thus creating a negative balance. Another study done by the Department of Agriculture (2000) indicated that out of 9,827 samples, 48.2 percent, 64 percent, and 35 percent samples were low in carbon, N, and K, respectively. It was further noted that the chemical fertilizers added to the soil were only the major nutrients such as nitrogen, phosphorus, and potash. Micronutrients such as zinc (Zn), boron (B), and molybdenum (Mo) are becoming more deficient, and the symptoms are more and more visible in sensitive crops like fruits and vegetables.

**Water Degradation**

Water quality is related to chemicals in the water used in agriculture, which can otherwise pollute water affecting human and animal health. Modern agriculture has advocated the use of these chemicals to improve productivity. The use of chemicals in agriculture is reported to be increasing in Nepal (Table 3). Chemicals are used as either fertilizers or pesticides. Nitrogen fertilizer can create nitrate pollution through leaching as well as surface run-off and can be harmful to drinking water causing “blue baby” disorder in humans and also, if in excess, to plant growth. Another important nutrient source is phosphorus which can build up in ponds and water reserves to create eutrophication, which creates unwanted growth of aquatic plants that can damage the environment and be harmful to human drinking supplies and fish cultivation. Additionally, chemicals used and produced in industries can also be potentially toxic to the plants and human and animal health. Industrial pollutants of heavy metals like mercury, cadmium, and lead, which get washed away into the soil can become toxic to the plants. Sulfur emissions from industries, which develop into acid rain, can also be harmful to the forest as well as agriculture. Similarly, studies indicate that arsenic-rich ground water systems cause arsenic-related diseases when consumed by humans. Moreover, arsenic intake through the food chain, particularly from rice grown with arsenic-contaminated irrigated water, would be alarming to the people of Nepal (Duxbury and Zavala, 2005). Water degradation can also be mapped when the source of irrigation water comes from lime-rich rock belts. A typical example can be cited from the water of the Seti River in the Pokhara Valley, which contains a high amount of free calcium carbonate. Using highly alkaline water that’s not suitable for crop cultivation can cause a cementing (binding) property in the plant root zone when irrigated thus restricting the root and shoot growth.
Table 3. Estimates of the use of chemicals.

<table>
<thead>
<tr>
<th>Year</th>
<th>Pesticides imported/sold* (a.i. tons)</th>
<th>Pesticide used in agriculture* (a.i. tons)</th>
<th>Fertilizer consumption** ('000 tons)</th>
<th>Nutrient consumption** ('000 tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1997</td>
<td>56.17</td>
<td>-</td>
<td>242.41</td>
<td>133.25</td>
</tr>
<tr>
<td>1998</td>
<td>77.86</td>
<td>77.86</td>
<td>307.07</td>
<td>169.66</td>
</tr>
<tr>
<td>1999</td>
<td>108.43</td>
<td>98.65</td>
<td>378.42</td>
<td>209.98</td>
</tr>
<tr>
<td>2000</td>
<td>196.07</td>
<td>176.00</td>
<td>430.47</td>
<td>239.10</td>
</tr>
<tr>
<td>2001</td>
<td>146.16</td>
<td>156.43</td>
<td>140.77***</td>
<td>78.18***</td>
</tr>
<tr>
<td>2002</td>
<td>177.59</td>
<td>141.88</td>
<td>174.38***</td>
<td>90.87***</td>
</tr>
<tr>
<td>2003</td>
<td>176.38</td>
<td>183.66</td>
<td>157.1***</td>
<td>87.5***</td>
</tr>
</tbody>
</table>

** includes both the official and cross border flow (ANZDEC, 2002).
*** includes only the official figure (A-BPSD, 2004).

The increased application of modern pesticides has also been the source of water pollution and once in the drinking water, there are harmful effects to human and animal health. The consumption of pesticides in accessible areas was found to be over 142 grams per hectare (g/ha) (Plant Protection Directorate, 2003). The use of pesticides is still not to that of a damaging level as in other countries, but the increased trend is alarming in areas where the cultivation of commercial crops has gained significant coverage (Table 3). Crops such as vegetables, fruits, tea, sugarcane, and other commercial crops have been the major commodities that use pesticides.

**Air Degradation**

Air degradation is also closely linked with the modern developmental process conducted by anthropogenic activities. It is also the process resulting in the climate change and global warming that are not widely discussed in public forums in Nepal. It is the ever-increasing concentration of greenhouse gases (GHGs) such as CO₂, methane, N₂O, SO₂, and hydrofluorocarbons made by human activities in which some are beneficial and some are harmful. However, all are contributing to global warming resulting in shifting plant and animal habitats, species destruction, and even threatening the survival of the agriculture system.

Among the GHGs, carbon dioxide can lead to an increase in biomass production of several agricultural crops, particularly C3 species, but at the same time can increase the atmospheric temperature. According to the World Meteorological Organization (WMO)/ United Nations Environment Programme (UNEP) Intergovernmental Panel on Climate Change (IPCC) predictions, the global temperature could increase from 1.5 to 4.5 °C by the end of the 21st century. This increase in temperature will likely cause biomass destruction or unbalancing the source-sink relationship.

Our model-based studies have shown that the C4 plant species are more affected by the climate change process due to the temperature rise (DHM and MOPE, 2004). The other GHGs that could be potentially harmful to human and animal health and to plant species are methane, nitrous oxides, and hydrofluorocarbons that also cause damage to the ozone layer. Similarly, the contamination of air due to the industrial sulfur emissions causing acid rain might impact
biomass destruction. Furthermore, the climate change process has become a contributing factor in causing extreme events like floods, droughts, and cold waves detrimental to agriculture. One can only imagine what the consequences would be for natural eco-systems and on the socio-economic well-being of human societies. At this stage, Nepal is certainly not a contributor to the global warming but suffers from its consequences. The more temperature-sensitive highland livestock, such as yaks and mountain goats, will likely have their habitat threatened due to global warming. However, due to the modernization process there have been changes in the livestock-based socio-economic activities of local peoples and this will impair the associated economic prosperity, but has not yet been well studied.

The national study conducted by DHM and MOPE (2004) indicated that the total methane emission for 1994 from domestic livestock enteric fermentation was estimated to be about 528 Gg (61 percent of the total) as shown in Figure 2. Non-diary cattle contribute 280 Gg or 53 percent of the total emission from livestock enteric fermentation while buffalos contribute 32 percent. Secondly, the total methane emission from paddy fields in 1994 was estimated to be 306 Gg or about 35 percent of the total methane emission from the agricultural sector. Irrigated rice is the major source of methane emission in rice cultivation. The rice area under different water regimes is given in Table 4. Thirdly, emissions from domestic livestock manure management are estimated to be 34 Gg (4 percent of the total). Dairy cattle contribute 15 Gg (44 percent of the total); non-dairy cattle 26 percent, buffalo 21 percent, and swine 1 percent.

Nitrous oxide emissions are primarily due to the use of fertilizers, which include synthetic nitrogen fertilizers, synthetic multi-nutrient fertilizers, and organic fertilizers. Total nitrous oxide emissions from agricultural soil management system in Nepal are about 27 Gg. Included among the various processes are the indirect nitrous oxide emission from grazing animals, pasture and paddock (41 percent), direct from agriculture fields (31 percent), and indirect from atmospheric deposition NOx and leaching of NH3 (28 percent) (Figure 3; DHM and MOPE, 2004).

![Figure 2. Methane emission from different agricultural activities for 1994. Source: DHM and MOPE, 2004](image-url)

Table 4. Area and percentage under different irrigation regimes.

<table>
<thead>
<tr>
<th>Water management regime</th>
<th>Harvested area (m² x 10⁹)</th>
<th>Percent of total area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigated continuously flooded</td>
<td>3.1474</td>
<td>24</td>
</tr>
<tr>
<td>Rainfed flood prone</td>
<td>1.0947</td>
<td>8</td>
</tr>
<tr>
<td>Rainfed drought prone</td>
<td>9.0316</td>
<td>68</td>
</tr>
</tbody>
</table>


**Biological Diversity Degradation**

In the past century, the reduction of biological diversity had been the course for the developed countries that were able to obtain the maximum genetic gain for commercial venture but by decreasing their own resources. The modern farming system focused on the exploitation of hybrid technology, a strong business sector in agriculture. They then searched in the developing world where the value of genetic diversity was little recognized or little exploited. A few countries like China, India, Brazil, and Mexico voiced their strong protest to make necessary provisions in international forums to protect rights of genetic resources at the area of origin and benefited by sharing with the local and indigenous people.

At the Earth Summit, the first of these formal commitments was the signing of the Convention on Biological Diversity (CBD). The genetic exploitation and reduction in the areas of origin began increasing. In the face of globalization and the development process, there is starting to be a reduction of biodiversity in Nepal also. Many of the original Nepalese rice varieties are vanishing and completely out of the reach from our farmers. Many aromatic local rice varieties are on the verge of extinction. Wheat varieties have been completely replaced by the imported modern varieties in the name of progress. Pure local maize cultivars are difficult to find even in the remotest areas due to the competition between the local and introduced cultivars. Many local potato cultivars are difficult to name and can only be recalled by elderly people. Most of these cultivars are now found only in the gene or seed bank thorough “ex-situ” conservation. We even failed to utilize them in our breeding efforts by recognizing their valuable attributes. Almost 26 livestock species are said to be on the verge of extinction or listed as endangered.
Nepal is a signatory to the Convention on the International Trade in Endangered Species of Wild Fauna and Flora (CITES); there are at least 129 species of plants and animal species in Nepal listed in the various categories of CITES Appendices (Table 5). Similarly, the International Union for Conservation of Nature (IUCN) lists at least 120 plants and animal species in different threatened categories (Table 5).

Table 5. Threatened plant and animal species of Nepal.

<table>
<thead>
<tr>
<th>Species</th>
<th>CITES I</th>
<th>CITES II</th>
<th>CITES III</th>
<th>Total</th>
<th>Ex</th>
<th>V</th>
<th>R</th>
<th>I</th>
<th>K</th>
<th>T</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>V. Plants</td>
<td>1</td>
<td>8</td>
<td>6</td>
<td>15</td>
<td>1</td>
<td>11</td>
<td>22</td>
<td>2</td>
<td>5</td>
<td>7</td>
<td>60</td>
</tr>
<tr>
<td>Mammals</td>
<td>29</td>
<td>7</td>
<td>22</td>
<td>58</td>
<td>8</td>
<td>10</td>
<td>4</td>
<td>5</td>
<td>1</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>Birds</td>
<td>16</td>
<td>9</td>
<td>15</td>
<td>40</td>
<td>6</td>
<td>6</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>Reptiles</td>
<td>7</td>
<td>4</td>
<td>2</td>
<td>13</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amphibians</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Insects</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Totals</td>
<td>53</td>
<td>31</td>
<td>45</td>
<td>129</td>
<td>1</td>
<td>27</td>
<td>30</td>
<td>28</td>
<td>13</td>
<td>13</td>
<td>8</td>
</tr>
</tbody>
</table>


Productivity Degradation

Agriculture has survived the legacy of various historical processes and continues to produce more and more. On the global scale, it is claimed that food production has been successful in meeting the growing population of the world. In the case of Nepal also, some statistics show a trend of productivity gain in most of the crops but at what cost? The green revolution added a few kilograms of grain yields per hectare but at what cost? Modern agriculture added more amounts of fertilizer to get more outputs but at what cost? We added more amounts of pesticides not thinking of what its environmental consequences would result in but at what cost? We ignored the eco-system balance between all living entities. We kept on ignoring these issues to the detriment of our future generations. We tried to move away from nature to obtain short-term benefits at the cost of a sustainable developmental paradigm.

Several studies also support the fact that there has been a gradual decline of productive capacity of our soils (Sherchand, 2004; A-BPSD, 2004; and Sherchand, 2001). In some cases, the soil and nutrient exhaustion is so acute that many crops are not thriving for the lack of balanced use of fertilizers. The productivity degradation can also be mapped by showing the existing gap between what we have and what it ought to be; between what it is and what its potential would be. The model evaluation figures out that those yield gaps are not showing signs of significant improvement (Table 6).

Table 6. Yield Gaps (t/ha) between potential, attainable, and national of Nepal.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Potential*</th>
<th>Attainable**</th>
<th>National***</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice</td>
<td>10.0</td>
<td>7.0</td>
<td>2.68</td>
</tr>
<tr>
<td>Maize (OPV)</td>
<td>7.0</td>
<td>5.0</td>
<td>1.88</td>
</tr>
<tr>
<td>Wheat</td>
<td>6.0</td>
<td>4.0</td>
<td>2.01</td>
</tr>
</tbody>
</table>

Classical experimental evidence derived from long-term rice-wheat production shows that the nutrient depletion from our agriculture system doesn’t support the sustainability of our cropping system. Figure 4 shows that the rice yield continued to decline from 5 t/ha to 1 t/ha when soils are not replenished adequately and some other macro- and micro-nutrients were exhausted affecting the productive capacity of our soils (Regmi, et al., 2004).

![Grain yield of rice declines if the nutrients are not replenished properly](image1)

![Grain yield of rice recovers by replenishment of nutrients](image2)

Figure 4. Yield declines over years if nutrients are not properly replenished (Regmi, et al., 2004).

**Social and Cultural Degradation**

The institutions of social and cultural assets have remained as the custodian of natural resources and their management. Those institutions evolved through the legacy of preserving indigenous and traditional ecological knowledge systems to integrate them into the rural economy. Those institutions served as the key players, regulating when needed, and continuing to meet the local needs. They knew better than any other entities when to integrate land, water, forest, grassland, and livestock supporting the agriculture system.

In parts of the country, the locally adopted electoral systems (the local administrative institution) have played the central role in the decision-making process in natural resource management. The indigenous systems still play customary roles, although the state-owned local institutions are in place. They hold the respect of communal philosophy based on the social and cultural values and deserve a deciding role in managing natural resources. It is ironic that those state-run institutions are kept in the shadows of the indigenous institutions. Those indigenous authorities are respectfully elected from the people whereas, the state-controlled institutions are politically flawed and do not recognize just, moral, and ethical values. However, in the domination of state local administration, those traditional institutions started gradually breaking away.

The forest, soil, and water management, for instance, were more efficient in the hands of those indigenous and customary institutions. When the forest was nationalized in the early 1960s, the local people were simply ignored. The forest resources underwent a rapid degradation process in the hand of government authorities. Later the government was forced to introduce a community and participatory forest-management system, derived from indigenous forest management. In this sense, the community-based farming system has a legacy as opposed to the modern institutions particularly in the more mountainous areas. The gradual shift from family to corporate-based farming systems has been the characteristic of the modern development process and can be a detriment to social and cultural cohesions.
Livestock

Livestock contributes currently 31 percent of the Agricultural GDP and the Nepalese Agriculture Perspective Plan (APP) envisages increasing this to 45 percent with an accelerated growth rate from 2.9 to 6.1 percent at the end of the planned period. Nearly 12 percent of the total land area (147181 km²) is available for livestock grazing in the country (A-BPSD 2001). The livestock development plan however is based on the parallel growth of the crop sector, market demand, lifestyle change, and private sector investment.

The country has experienced an unbalanced pressure on the grazing lands due to the increased number of unproductive livestock population. A strong imbalance exists between livestock population and grazing land. The alpine region, which has 63.8 percent grazing land, has only 13.4 percent of the livestock population. The sub-tropical belt, which has 34.4 percent of the livestock, has 22.5 percent grazing land (Table 7); but the sub-temperate region has 42.2 percent if the livestock but only 13.7 percent of the grazing land. The balance should come either from crop residues, concentrates or forest resources. The crop residues do not meet the requirement, and it is mostly limited to commercial stall-feeding. This in turn puts pressure on the forest. This would again force the farmers to exploit more forest and upset carbon sequestration. And the current stocking density is exceeding the carrying capacity except in the alpine region (Table 8). The grazing of livestock has exerted intense pressure in the mid-hills and the open grasslands.


<table>
<thead>
<tr>
<th>Ecological Region</th>
<th>Livestock Percent</th>
<th>Grazing Land Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-tropical</td>
<td>34.38</td>
<td>22.5</td>
</tr>
<tr>
<td>Semi-temperate</td>
<td>52.22</td>
<td>13.7</td>
</tr>
<tr>
<td>Alpine</td>
<td>13.40</td>
<td>63.8</td>
</tr>
<tr>
<td>Total</td>
<td>100.00</td>
<td>100.00</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Range land type</th>
<th>Carrying Capacity LU/ha</th>
<th>Stocking Density LU/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mid-Hills</td>
<td>0.31</td>
<td>4.08</td>
</tr>
<tr>
<td>Steppe grasslands</td>
<td>0.01</td>
<td>0.19</td>
</tr>
<tr>
<td>Open grasslands</td>
<td>0.54</td>
<td>7.07</td>
</tr>
<tr>
<td>Alpine meadows</td>
<td>1.42</td>
<td>0.64</td>
</tr>
</tbody>
</table>

Climate

The monsoon is the most dominant climatic event in Nepal, which has a direct relationship with the rice production system. The productivity of rice directly depends on the monsoon both spatially as well as temporally. Nearly two-thirds of the total land is rain-fed or partially irrigated. Thus agriculture is largely determined by the weather conditions. The production of rice, for instance, increased more than expected in 2000, which was largely attributed to favorable weather conditions. On the other hand, the 2002 monsoon created a high uncertainty with nearly 40,000 ha of rice under water due to floods in the eastern areas of Terai, and 20,000 ha under drought in the
western Terai. The variability of the onset of the monsoon in the central part of Nepal which determines the rice planting is given in Figure 5.

![Figure 5. On-set of monsoon variability. Source: DHM, 2005.](image)

The erratic climatic behavior commonly known now as cold wave is being experienced in the country causing damage to human and animal lives and winter crops. In the 1997/98 winter, the Indo-Gangetic plain including part of Terai experienced severe overcast skies. The temperature dropped to a minimum level and winter crops especially potato, oilseeds, pulses, tomato, onion, etc., were affected. The potato yield dropped by at least 28 percent, mustard (*Brassica campestris* var. *toria*) by 37 percent, sarson (*Brassica campestris* var. *sarson*) by 11 percent, rayo (*Brassica juncea*) by 30 percent, lentils by 38 percent, and chickpeas by 38 percent (Table 9). The severe market shortage caused the price hike of these crops to reach very high levels. This prompted the farmers to change the cropping pattern the following year.

**Managing the Resources**

The peoples’ concern in managing our own natural resources is considered vital. However, the problem pivots on how to retain the balance between consumption and conservation. It is ironic that the much discussed Nepalese APP has failed to address natural resources management and land use policy in the broader context. Resource exploitation has been the prime commercial objective in reviewing or protecting the fragile mountain ecosystem. The proportional relationship among land, water, forests, and their supporting and dependent entities is kept silent in the name of commercial exploitation.

There are differences in how Nepalese farmers manage to recycle farm resources compared to how farmers in developed countries manage them. We use a crop-residue-livestock system and give back to the land in a cyclic manner. This works so long as the livestock population remains as a stable fixture of the farm household economy. On the other hand, in the commercial agriculture of developed countries, farmers recycle by leaving a major portion of crop stubble
and residues in the field and allowing them to decompose before the next crop season. Regretfully, our scientists and development workers fail to teach this and provide a balanced use of nutrient sources to our stressed farmers. The farmers are even more stressed and unable to bear the risks due to the compounding effects of social, cultural, and economic taboos.

Table 9. Impact of cold wave on winter crop yields estimated in the Terai of Nepal, 1997/98.

<table>
<thead>
<tr>
<th>Year</th>
<th>Potato (t/ha)</th>
<th>Mustard (kg/ha)</th>
<th>Sarson (kg/ha)</th>
<th>Rayo (kg/ha)</th>
<th>Lentil (kg/ha)</th>
<th>Chickpea (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1987/88</td>
<td>960</td>
<td>539</td>
<td>1320</td>
<td>601</td>
<td>539</td>
<td>1320</td>
</tr>
<tr>
<td>1988/89</td>
<td>703</td>
<td>563</td>
<td>728</td>
<td>844</td>
<td>819</td>
<td>709</td>
</tr>
<tr>
<td>1989/90</td>
<td>25.54</td>
<td>503</td>
<td>844</td>
<td>819</td>
<td>709</td>
<td></td>
</tr>
<tr>
<td>1990/91</td>
<td>19.72</td>
<td>570</td>
<td>912</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1991/92</td>
<td>22.28</td>
<td>949</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1992/93</td>
<td>17.36</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1993/94</td>
<td>22.13</td>
<td>712</td>
<td>785</td>
<td>601</td>
<td>1044</td>
<td>999</td>
</tr>
<tr>
<td>1994/95</td>
<td>23.76</td>
<td>718</td>
<td>524</td>
<td>548</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1995/96</td>
<td>17.21</td>
<td>760</td>
<td>636</td>
<td>565</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1996/97</td>
<td>22.63</td>
<td>815</td>
<td>803</td>
<td>887</td>
<td>959</td>
<td>922</td>
</tr>
<tr>
<td>Mean</td>
<td>21.33</td>
<td>747</td>
<td>569</td>
<td>733</td>
<td>807</td>
<td>999</td>
</tr>
<tr>
<td>1997/98</td>
<td>15.39</td>
<td>474</td>
<td>505</td>
<td>513</td>
<td>504</td>
<td>619</td>
</tr>
<tr>
<td>% Reduction</td>
<td>27.8</td>
<td>36.5</td>
<td>11.2</td>
<td>30.0</td>
<td>37.6</td>
<td>38.0</td>
</tr>
</tbody>
</table>


The natural water resources are still abundantly available and mostly untapped. Nepal, except in a few areas, has an annual average rainfall of 1,450 millimeters (mm) which is considered theoretically enough for growing major crops. Yet, an uneven distribution of rainfall and its erratic behavior is compounded by global climate change causing flooding on one hand and drought on the other. This surely demands a careful management of water resources. Rain-fed agriculture still dominates the production capacity of the land. According to the Nepalese Irrigation Department, about 40 percent of the total land has irrigation structures but year-round irrigation is still rather distant. To acquire sound irrigation systems or to avert the process of water scarcity, four options could be considered: expansion of surface irrigation; exploitation of ground water; rainwater harvest; and the improvement of water use efficiency through proper on-farm water management. The new and emerging on-farm water management has sent an encouraging message to the benefit of agriculture which would complement the efforts of our water-structure engineers.

There are at least 132,000 biogas plants in Nepal, which have a potential of producing 760,000 tons of slurry annually. This could be used to manure 76,000 ha of cropland. The nutrient content of slurry has been proven to be qualitatively better and yielding by an average of 10-15 percent more than the normal farmyard manure (Karki, 2002). However, the use of slurry in farm production has not gained momentum for its lack of proper knowledge among the farmers.

Nepal also houses a large number of unproductive domestic animals, which are also responsible for emitting methane gas without offering much to the national economy. The methane emission in Nepal is estimated to be 100 grams per kilogram of milk production compared to less than 25
grams in the developed countries (Stem, et al., 1995). Those unproductive animals should be gradually curtailed to reduce the environmental risks.

**Indigenous and Local Ways of Resource Management**

The legacy of natural resource management in agriculture continues with prevailing farming systems. The performance of natural resource management that uses the local resources became more prominent in the mountains and hills through various institutions linked by a notion of “commons,” which are owned by the local community as a whole. The resources ranging from land, water, forest, pasture, even labor and capital are the key constituents that remain under the functionaries of local institutions. A few noteworthy examples include the following: terracing and bunding, rain water harvesting for rice transplanting, protection from erosion, rotational grazing, rotational irrigation, ridge planting of fodder trees and their nutrition, evaluation of land quality, seasonal herding of highland animals, compost making, and use of local plant species to reduce the attack of pests. Similarly, rotational farming, particularly in the eastern Himalaya and the hills of Nepal, is often left unrecognized by state authorities since it is believed to be unsustainable farming, yet it has the strong legacy among indigenous people. However, there is now an increased sense of revitalization of its importance in sustaining the natural resource management through the built-in community cohesion (IAITPTF, 2002, and Kerkhoff, 2004).

Gill (1993) who fears the damage of ignoring the indigenous systems has suggested that it be seen as having both strengths and weaknesses since it has evolved and lived for generations in sustaining their livelihoods. To keep the rural economy going forward, indigenous people use their own human and social capital, labor, and draft animal management through an exchange popularly known by “perma,” which has become highly recognized. Furthermore, in order to fulfill their own basic needs, the Nepalese exchanged grains and services, which later developed into a mode of financial capital formation. This sort of capital formation is popularly known as “dhikuri” and has spread not only in the rural but also in the urban economy. There has also been the debatable notion that rural people in Nepal have evolved the theory of “tragedy of commons,” which assumes that common ownership always facilitates the degradation of resources. On the contrary, few ecological and social scientists have contradicted this as opposed to the commercial exploitation and the view that the corporate institution matters more than the common ownership which causes degradation (Fisher, 1992).

**Emerging Technologies**

Emerging resource conservation technologies developed by our scientists in Nepal and elsewhere have been tested in research centers and are in the stage of being validated in farmers’ fields through a participatory extension approach. Among the noteworthy technologies are zero tillage in wheat and other crops, surface seeding in wheat, and bed planting in rice and wheat. These technologies have proven to be cost-effective and efficient in the use of scarcely available water and for carbon sequestration; they also cause minimum water and wind erosion damage, etc. Currently, rice and wheat area under zero or reduced tillage exceed 2.5 million ha in South Asia, and claims are being made that it’s reducing costs by 40 percent and water usage by 30-60 percent. Bed planting also covers about 1,000 ha in India and Pakistan but significantly less in Nepal. Surface seeding of wheat in high-moisture lowlands has proven to be allowing timely
planting of wheat and compensating the loss of wheat yield. All of these technologies have the additional advantage of saving time as compared to conventional methods, which becomes important under tight cropping practices. Table 10 shows the comparative advantages of these newer technologies over the traditional practices.

Table 10. Advantages of frontier technologies in crop production.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Area in Nepal (ha)</th>
<th>Crop</th>
<th>Cost saving %</th>
<th>Water saving %</th>
<th>Time saving %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface seeding</td>
<td>Wheat</td>
<td>100</td>
<td>100</td>
<td>60-100</td>
<td>80</td>
</tr>
<tr>
<td>Zero tillage</td>
<td>50 wheat, lentil</td>
<td>40</td>
<td>40</td>
<td>30-60</td>
<td>80</td>
</tr>
<tr>
<td>Bed planting</td>
<td>10 Wheat</td>
<td>0</td>
<td>0</td>
<td>30-60</td>
<td>10</td>
</tr>
<tr>
<td>Two-wheeled tractor rotator</td>
<td>early stage wheat</td>
<td>30-40</td>
<td>30-40</td>
<td>10-20</td>
<td>40</td>
</tr>
<tr>
<td>Two-wheeled tractor reduced till drill</td>
<td>early stage wheat, rice lentil, mustard</td>
<td>60</td>
<td>20-30</td>
<td>70</td>
<td></td>
</tr>
</tbody>
</table>


The Global Voice

In the process of globalization, competitiveness prevails as the deciding factor. Competitiveness causes exploitation and the selling of user’s rights related to the intellectual properties. In such situations, some are winners and some are losers leading to the uneven distribution of wealth and resources. Social and cultural values and mutual respect are not recognized but rather invites overexploitation leading to exhaustion. On one hand, this offers an opening to trade our resources in the international markets, but on the other, it will likely eliminate the rights of our farmers and the indigenous peoples who had been conserving these resources and associated knowledge. This is why it is particularly important to maintain biodiversity, which the farming and indigenous communities have been doing through the centuries.

The provision of intellectual property rights at the cost of the traditional community does not seem to be in conformity with the people’s aspirations. Although the international conventions like the Convention for Biological Diversity (CBD) has provision for the recognition of indigenous knowledge, ownership, and benefit sharing, and even offers an alternate way of defining the “sui generis” system, and subsequently the FAO’s “farmers right;” we have yet to see something worked out by the state for meeting the people’s perspectives in Nepal. This is still a dream due to the lack of legal provision and necessary ground work at the national and local levels. Furthermore, the provisions made in the Kyoto Protocol for Clean Development Mechanisms (CDM) that could be achieved through afforestation and reforestation, do not really seem to be in conformity with the CBD to protect the biological diversity and benefit sharing (Sherchand, 2002).

Competition on the one hand provides an occasion to use more chemical based inputs, but on the other, there is also a need to produce environmentally healthy foods. Globalization and economic prosperity have become a major force in determining which type of food society needs. In due course, the market-induced commercial agriculture has been gradually taking shape, often undermining the subsistence or nature-based agricultural system. Commercial
agriculture promotes the use of chemicals to boost more production. Similarly, the genetically modified seeds have provoked the environment with an unfriendly production system ignoring the human and natural survival relationship. Despite all of this, there has also been an increased demand in natural-based products such as chemical-free fruits, vegetables, orthodox tea and coffee, and honey, etc. But the success and expansion of these products have not been as wide as their production, consumption, and marketing; and they depend on the consumers’ choice in consonance with their economic status and awareness. At the growing level of import-export demand, Nepal has to face the non-tariff barriers in agriculture such as technical, sanitary, and phyto-sanitary in pursuance of the global trade regimes. To promote and comply with the international trade-related treaties, the state should be prepared to put the regulatory mechanisms in place, promote public awareness, and promote technical and institutional support.

Natural farming in the present context of environmental management in agriculture has been a rising voice in urban and more elite sectors of the society. Many innovative ideas are emerging such as permaculture, effective microorganism (EM) technology, vermiculture, organic or natural farming, ecological farming, and model bio-villages, etc. Those technologies have their own constraints and are confined to a limited area but could not become widespread, regardless of our discussion of the benefits. Definitely, these technologies could pave a pathway among the small-scale but more innovative farmers.

Population and Food Provision

Food security can perhaps be more appropriately defined in terms of food provision in the context of the globalization process, or the access to and availability of food. This demands not only adequate production but also the improved economic gain to buy food. Ironically, for a country like Nepal, the greatest challenge is managing the provision of food and population. According to a medium-population growth rate, Nepal’s population will likely double in the next 30-35 years; if food demand remained at a modest level that would mean about 15 million tons. The current food production level is almost in balance with the needs of the population. However, the food needs of the population will not be met if there is some natural, economic, or political crisis. If this remains the national picture, Nepal will ultimately become a food importing country. Table 11 clearly indicates that there have been either decreased or stagnant trends of food production in response to the increased population growth. As a result, highland-to-lowland and rural-to-urban migration for off-farm economic activities have become a compelling factor. Furthermore, it is increasingly evident that the younger generation is moving out of or not going into farming as a profession, leaving the aged, women, and children as a major source of farm employment.

<table>
<thead>
<tr>
<th>Year</th>
<th>Population (million)</th>
<th>Rice</th>
<th>Maize</th>
<th>Wheat</th>
<th>Potato</th>
<th>Oilseeds</th>
<th>Pulses</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1961</td>
<td>9.41</td>
<td>224</td>
<td>90</td>
<td>15</td>
<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
<td>328</td>
</tr>
<tr>
<td>1971</td>
<td>11.56</td>
<td>203</td>
<td>66</td>
<td>19</td>
<td>25</td>
<td>4.9</td>
<td>n.a.</td>
<td>318</td>
</tr>
<tr>
<td>1981</td>
<td>15.02</td>
<td>170</td>
<td>50</td>
<td>35</td>
<td>21</td>
<td>5.3</td>
<td>8.8</td>
<td>291</td>
</tr>
<tr>
<td>1991</td>
<td>18.49</td>
<td>174</td>
<td>65</td>
<td>42</td>
<td>40</td>
<td>4.8</td>
<td>8.4</td>
<td>334</td>
</tr>
<tr>
<td>2001</td>
<td>23.15</td>
<td>180</td>
<td>65</td>
<td>54</td>
<td>64</td>
<td>5.8</td>
<td>10.8</td>
<td>338</td>
</tr>
</tbody>
</table>

The complementarities and renewed relationships between agriculture, forest, and livestock managed by the farmers should not be allowed to turn into a desperate situation. A healthy agriculture system demands to be revitalized and relationships reasserted. There should be a win-win situation between conserving resources and boosting agriculture production. This should therefore remain the case for sustainable agriculture development.

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References


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Abstract

The Upper Klamath Basin, Oregon, USA, is an area of major issues and severe conflicts in water management and use, which also has high political visibility. A key need in promoting sustainable agriculture in this area is hydrologic tools and models that can be used for producing streamflow forecasts, predicting the effects of land management and irrigation practices, and obtaining a better understanding of the basin’s hydrology. Semi- and fully distributed hydrologic simulation models are being investigated for these purposes in the Sprague River catchment, a major tributary in the basin. These models require considerable spatial data input preparation, both for watershed characteristics and the meteorological forcing data. Model validation is accomplished by comparing simulated with observed snowpack at meteorological stations, comparing simulated snow fields with satellite snow covered area images, and comparing simulated with observed hydrographs at the catchment outlet. The application of these models is challenging due to the complex hydrology and high degree of spatial and temporal climatic variability in the basin, so there are interesting scientific issues to be addressed while at the same time producing tools of practical value.

Introduction

One important element affecting sustainability in agricultural areas is how the water resources are managed. Efficient and effective water management is based on a solid understanding of the hydrology of the area and the ability to predict the availability of water. Mathematical models are the vehicle into which this hydrologic understanding is embedded and from which hydrologic predictions can be made.

In western North America, much of which is arid or semi-arid, agriculture is predominantly based on irrigation. Surface water is the main source for irrigation, and much of this water derives from snowmelt. Predictions of the spring and summer snowmelt streamflow, then, are key to managing the water and to crop choice and planting decisions. In addition, management of on-farm water, particularly regarding the irrigation methods used, and the management of reservoirs affect the efficiency of water use. Other hydrologic and ecosystem issues can also be important considerations, such as the effect of vegetation and land management within the catchment area and riparian zones on water yield, and the instream flows made available for the support of fish populations. On a broader timescale, an understanding of and ability to assess the hydrologic effects of climate teleconnections, climate variability, and climate warming are
essential in not only year-to-year water management but also the development of long-range planning and management policies.

The Upper Klamath Basin of southern Oregon in the United States is an irrigated agricultural area in which all of these issues are of concern and in which conflict over water is particularly severe. It is highly visible area politically and has received much publicity. It is therefore an area worthy of special focus from a hydrologic point of view. The U.S. agency responsible for managing the irrigation water resources of the basin, the Bureau of Reclamation, is keenly interested in improving the ability to understand and predict the water yield. This is the primary motivation for the investigation into the application of hydrologic simulation models in the Upper Klamath Basin described in this paper.

**Upper Klamath Basin and Sprague River Description**

The basin of interest is the drainage area to Upper Klamath Lake (Figure 1). This is the water source for the irrigated areas to the south and is regulated by the Bureau of Reclamation. The two main tributaries are the Williamson River, which drains the northern part of the basin and enters the lake south of the town of Chiloquin; and the Sprague River, which drains the northeastern part of the basin and flows into the Williamson River near the town of Chiloquin. Together, these two rivers represent 79 percent of the Upper Klamath Lake drainage area (7,770 out of a total of 9,869 kilometers² [km²]) and 59 percent of the average annual streamflow (989.2 out of a total of 1,685.9 million meters³ [m³], base period 1971-2000).

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**Figure 1. Upper Klamath Basin showing Natural Resources Conservation Service data sites.**

The focus of the hydrologic modeling is the Sprague River, with a drainage area of 4053 km² and an average annual streamflow of 567.1 million m³. Much of the catchment is dry plateau, and mountains form the northern and eastern drainage divide. Elevations range from 1,284 to 2,525 m, with an average elevation of 1,600 m.

**Hydrologic Modeling**

**Goals**

There are several goals to be accomplished by the application of hydrologic simulation models in the Sprague River and eventually the entire Upper Klamath Basins:

- In general, obtain a better understanding of the hydrology and water balance of the basin and develop the ability to represent this system in models.
- Apply and develop models with a strong physical basis and a high spatial and temporal resolution so that the hydrologic effects of vegetation and land use changes as well as climate variability and warming can be quantitatively evaluated.
- Evaluate the ability to simulate and forecast snowpack and streamflow using (1) a commonly used semi-spatially distributed conceptual model (Precipitation Runoff Modeling System [PRMS]; Leavesley, et al. 1983); and (2) newer, more physically explicit, fully spatially distributed (i.e., grid-based) models (Distributed Hydrology-Soil-Vegetation Model [DHSVM] and ISNOBAL; Wigmosta, et al. 1994 and Marks, et al. 1999, respectively).

The goals having to do with assessing vegetation and land use changes (specifically, removal of juniper trees that have encroached onto rangelands, restoring riparian areas and wetlands, and switching from flood to sprinkler irrigation) are part of a project under the Conservation Effects Assessment Project (CEAP), which is a major effort by the U.S. Department of Agriculture to assess quantitatively the hydrologic and water quality effects of conservation practices on agricultural land (see links at http://www.nrcs.usda.gov/technical/nri/ceap/index.html). Part of this program consists of intensive modeling and monitoring studies in selected catchments around the country. One of these catchments is the Sprague River.

All of these goals are of interest to the Bureau of Reclamation that has sponsored two major studies currently being led by the author’s two agencies. They are anxious to obtain as much understanding and predictive capability as possible to assist them in managing the water.

**Spatially Distributed Modeling**

Spatially distributed hydrologic modeling has become more commonplace in the past decade or so. One possibility is what could be called a semi-distributed approach, such as what is done in PRMS, where the basic spatial unit is a Hydrologic Response Unit (HRU); each of which is defined as an area of the catchment that is approximately homogeneous according to some combination of one or more characteristics, such as topography, vegetation, soils, etc. Other models are fully distributed, that is, the basic spatial unit in the model is a grid cell, each of which contains its own unique set of characteristics.
In either case, the idea is to assign model parameters as much as possible from basic spatial layers of elevation, vegetation, and soils and values derived from them. This then helps minimize the number of parameters that must be estimated by calibration. Figure 2 shows the basic spatial data layers and the model parameter layers that can be derived from them.

![Diagram of basic spatial data layers and derived data layers](image)

**Figure 2.** Basic spatial data layers and the model parameter data layers commonly derived from them.

PRMS and DHSVM are both comprehensive hydrologic models containing all of the process components shown in Figure 3, although PRMS has simpler and more conceptual process algorithms than DHSVM. ISNOBAL (Figure 4) is a very detailed energy balance model of snowpack, but it does not contain the land surface components. It has been used successfully in several catchments (Marks, et al., 1999; Garen and Marks, 2005), so it is of interest to test in the Sprague River Basin and see how snowpack simulation compares to that of other two models.
Figure 3. Schematic depiction of hydrologic processes represented in spatially distributed hydrologic modeling, many of the parameters of which are derived from basic and derived spatial data layers.

Figure 4. Diagram of ISNOBAL model components (energy fluxes in normal type, water fluxes in italics). Source: Garen and Marks (2005).
Preparation of Spatial Meteorological Forcings
Hydrologic models require meteorological input forcing data. Older, simpler models were built to operate with just precipitation and temperature data as input, but this was in the era when these were the only station data available. Now, more data sites and variables are available, so these can be used to force spatially distributed models that have better physical process descriptions. The basic meteorological variables needed to force a physically based energy balance hydrologic model include:

- Precipitation
- Air temperature
- Solar radiation
- Thermal radiation
- Relative humidity
- Wind speed

These are needed at a daily to hourly time step. To obtain these spatial fields, interpolation of station data is necessary. Various procedures must be used, depending on the characteristics of each variable and the number of stations available (Garen and Marks, 2005). Below, the first three variables on the list above are discussed for illustration purposes.

Precipitation
Detrended kriging has been used successfully to compute spatial fields of daily precipitation in a number of studies (Garen, et al., 1994; Garen and Marks, 2005). This method is also being used in the Sprague Basin to prepare the precipitation forcings for PRMS, DHSVM, and ISNOBAL. The procedure begins with computing an elevation trend for each day, as illustrated in Figure 5.

![Figure 5. Precipitation in Sprague River catchment for January 1, 2004, showing elevation trend.](image-url)
The trend is subtracted from each station’s data to obtain residuals. These residuals are then used in an ordinary kriging algorithm to obtain an interpolated residual field. Finally, based on the digital elevation model, the elevation trend is added back to each grid cell’s kriged residual to obtain the precipitation estimate. The kriging algorithm places high weight on Silver Creek for the grid cells in this vicinity due to their proximity to this station, therefore the estimated residuals for these cells are also positive, making their final precipitation estimates also lie above the elevation trend line and producing this especially wet area in the precipitation field.

For PRMS, this field is spatially aggregated to correspond with the HRUs. For DHSVM and ISNOBAL, this spatial resolution is appropriate (i.e., grid cells), but the field must be temporally disaggregated to 3-hourly amounts, as these models are run at this computational time step (in contrast with PRMS, which is run at a daily time step in this work). Temporal disaggregation is accomplished with a simple fractioning scheme (Garen and Marks, 2005), which is used instead of interpolating the 3-hourly data directly due to excessive noise in the 3-hourly precipitation observations.

**Air Temperature**

The same detrended kriging procedure used for interpolating precipitation can also be used for air temperature. It can be used with daily data (maximum, minimum, average), as with precipitation, but, unlike precipitation, 3-hourly data can also be interpolated directly because temperature data are much more stable and contain much less noise than precipitation.

Figure 6 shows the 3-hourly average temperature station data and elevation trend for the period 1,200-1,500 on January 1, 2004, (the same day for precipitation shown in Figure 5).

**Solar Radiation**

Preparing solar radiation inputs for a hydrologic model requires a multi-step process combining the analysis of observations and the use of models. These steps are shown in the flowchart in Figure 7. This represents the processing steps used to prepare spatial net radiation forcings for ISNOBAL as developed by Garen and Marks (2005). The solar radiation and snow albedo models mentioned in Figure 7 are contained in the Image Processing Workbench (IPW) software package (http://cirque.nwrc.ars.usda.gov/~ipw). Note that this process is run at a 20-minute time step, but these fields are temporally averaged to obtain 3-hourly fields for model input. Solar radiation observations are used to compute the cloud cover correction factor in the third box of the flowchart by comparing observed values to modeled theoretical clear sky values. There are four stations in the Sprague River Basin that have solar radiation data beginning approximately in 2002. Of course, there are times of instrument outages and other data quality problems, which have to be dealt with when processing these data.
**Model Verification**

Several methods must be used to verify a hydrologic model, as no single test is adequate. Some examples of how spatial hydrologic models can be verified are shown below. Since simulations have not yet been done in the Sprague River Basin, examples will be given for the Boise River Basin in Idaho in the United States from Garen and Marks (2005).

![Diagram of temperature vs. elevation](image)

Figure 6. Air temperature in Sprague River catchment for January 1, 2004, 1,200-1,500, showing elevation trend.
Figure 7. Flowchart of net radiation calculations for each 20-minute time step when the sun is up for each grid cell within the catchment (IPW utility names in italics). Source: Garen and Marks (2005).
**Snow Model Verification at Meteorological Stations**

Snow water equivalent and snow depth observations at meteorological stations can be used to provide first-level model verification. Examples of this from the Boise River Basin, as given by Garen and Marks (2005), are shown in Figures 8 and 9. While these results are quite satisfactory, it must be remembered that there is a mismatch of spatial scale in this comparison. The basic spatial unit of the model is a grid cell (a 250-m square in this case), whereas these values are being compared to point measurements. One must expect some discrepancies, particularly if physical characteristics at the meteorological station are not representative of the grid cell as a whole. Nevertheless, these comparisons are useful in assessing model simulations.

![Figure 8. Observed, simulated (with ISNOBAL) snow water equivalent for water year 1998 at Jackson Peak SNOTEL site (elevation 2,155 m), Boise River Basin, Idaho. Source: Garen and Marks, 2005.](image-url)
Figure 9. Observed, simulated (with ISNOBAL) snow depth for water year 1998 at Jackson Peak SNOTEL site (elevation 2,155 m), Boise River Basin, Idaho. Source: Garen and Marks, 2005.

Areal Verification of Snow Model

Remotely sensed snow cover images can be used to verify the areal extent of simulated snowpack. The limitations of this verification method are that clouds can obscure the image, and the satellite cannot “see” snow beneath a forest canopy. Some of these problems are being addressed with continued research in remote sensing as well as with new spatial products that are composites of remotely sensed images and model simulations (e.g., products available at http://www.nohrsc.noaa.gov).

Verification of Hydrologic Model

The standard way to verify a hydrologic model is to compare observed and simulated streamflow at the catchment outlet. This verifies the overall, integrated catchment behavior and is the most important quantity with respect to managing surface water resources. It does not, however, verify spatial distributions of hydrologic quantities, such as streamflow from tributaries, soil moisture, runoff source areas, etc. Nevertheless, the integrated basin response is one test that must be met in verifying a hydrologic model.

Figure 10 is an example of observed and simulated streamflow for the Boise River basin for 1998, as given by Garen and Marks (2005). This verification was done primarily as a way to determine if the snowmelt input to the catchment was reasonable. Since the simulated flow
followed the rises and recessions of the observed hydrograph quite closely, this gave confirmation to the snowmelt simulation as well as the hydrologic model in general.


**Ensemble Streamflow Prediction**

An initial set-up and calibration of PRMS has been done for the Sprague Basin (Risley and Hay, 2006). Since this model is well-established and is embedded within a supporting software environment, the facilities exist to use the model right away in an operational forecasting mode, once the database and data quality infrastructure that supplies the necessary input data is in place (which is a major effort in itself).

The primary method for using simulation models for streamflow forecasting is the so-called Ensemble Streamflow Prediction (ESP) method. This involves running the model with observed meteorological forcings up to the current day then running multiple scenarios into the future, each scenario using the meteorological forcings from a different year in the historical record. These multiple scenarios can then be used individually as input to a water resources system operation model, or they can be analyzed statistically to obtain distributions of relevant hydrologic quantities, such as seasonal volumes, peak flows, dates to recession below criterion flows, etc.
Conclusion

Because of the competing water uses, conflicts, and high political visibility of the Upper Klamath Basin, there is much interest in how hydrologic modeling and streamflow forecasting can play a significant role in helping to understand, predict, and manage the water resources. Complex geology and hydrology coupled with high spatial and temporal variability of climate, however, make for a challenging environment in which to apply models.

By applying hydrologic simulation models in the Upper Klamath Basin, it is hoped that this will provide new tools for improving streamflow forecasts over what is possible with the current generation of statistical models as well as help with other land and water management questions. They also may be of help in setting policies regarding fish flow requirements and in assessing the effects of climate warming. These modeling efforts are therefore significant both for the scientific issues involved as well as for the practical relevance of the results.

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European Agrometeorological Perspectives  
on the Conservation of Natural and Environmental Resources  
in Harmony with Agricultural Production Systems

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Abstract

This paper summarizes some ideas about the basic tasks of agricultural meteorology in the present situation when agrometeorologists must face some new challenges. The scope of agricultural meteorology as many other applied disciplines has changed during the last decades. While the basic task of agricultural meteorology has stayed the same, the socio-economic expectations of society have changed in the last decades. It seems that the stress has somehow shifted from the increasing of yield towards sustainable development in agriculture. There is also an additional problem in that the focus of agrometeorological activities varies from region to region. This poses problems to international organizations. The basic aim of “agrometeorology” is to improve the applications of meteorology to agriculture and environment in reference to crop management, groundwater contamination by fertilisers and pesticides, erosion, etc. This paper provides an overview of various European agrometeorological activities in relation to the conservation of natural and environmental resources.

Introduction

In the framework of the World Meteorological Organization (WMO), there are several technical commissions that provide technical advice and direction to WMO members. The Commission for Agricultural Meteorology (CAgM) is one of these commissions and from time to time it organises working groups to evaluate the position of agricultural meteorology. Collecting the information to give a general answer is difficult because the problems are highly varied from regional association to regional association. The WMO as worldwide organisation would like to give useful information to every member. In this case, solving problems is a challenge because we can give mainly a philosophic approach, taking into consideration the complexity of the possible agrometeorological tasks we face with the scientific and user’s community. The role of the CAgM is to provide guidance in the field of agricultural meteorology by studying and reviewing available science and technology; to propose international standards for methods and procedures; to provide a forum for the examination and resolution of relevant scientific and technical issues; to promote training and the transfer of knowledge and methodologies; and to promote international cooperation and maintain close cooperation in scientific and technical matters with other international organizations.

A new working structure was established during the XIIIth session of the CAgM held in Slovenia in October 2002. Under the Open Programme Area Group (OPAG) 1, an Expert Team on the Management of Natural and Environmental Resources for Sustainable Agricultural Development
ETMNER) was established and was given seven basic tasks to answer the modern questions of agrometeorological activity from the point of view of environmental resources:

a) to assess and report on the appropriate agrometeorological criteria to conserve and manage natural and environmental resources for the benefit of agricultural, rangelands, forestry, and fisheries, and for other relevant rural activities;
b) to survey the status of and summarise the information on trends in land degradation at the national and regional levels;
c) to document case studies of successful measures to manage land use, protect land and mitigate land degradation;
d) to provide liaison with the Joint WMO/Intergovernmental Oceanographic Commission (IOC) Technical Commission for Oceanography and Marine Meteorology (JCOMM) on inter-commission activities on natural disaster reduction in coastal lowland areas;
e) to establish practical guidelines from an agrometeorological perspectives for the conservation of natural and environmental resources in harmony with agricultural production systems;
f) to establish operational guidelines for fire weather agrometeorology;
g) to prepare reports in accordance with timetables established by the OPAG and/or Management Group (MG).

The present paper tries to add some ideas to item “e.” In general, we state that the need for sustainable agriculture and the sustainable agriculture does not refer to a prescribed set of practices. A systems perspective is essential to understanding sustainability, encompassing the individual farm to the local ecosystem to the communities affected by the farming system.

Weather and changing climate are major factors affecting agricultural production in both developed and developing countries. Natural disaster mitigation plans should be factored into strategies for managing natural and environmental resources for sustainable agricultural development. These strategies for managing natural and environmental resources for sustainable agriculture can be achieved only through effective partnerships of experts from all disciplines and with all affected sectors of society.

The agrometeorological perspectives for the conservation of natural and environmental resources in harmony with agricultural production systems were outlined. We can define agrometeorology as an applied and crosscutting science. The first products in the field of agricultural meteorology were estimating yields, and then expanded to date of ripening, planning of planting, irrigation forecast, fertilizer, and plant protection. To solve these problems, scientists observed phenomena and measured standard meteorological values and special elements including evapotranspiration, soil moisture, and canopy fluxes. Also calculated were different variables and parameters. A major focus of the field was measuring and modelling the water budget of the soil-plant-weather system. Yield estimation can be performed using statistical or dynamic/simulation methods, which have quickly increased their role in relation to issues of climate change and extreme events in European agriculture.

From the point of view of the author, national co-operation is declining; therefore, international cooperation is increasingly important. Therefore, cooperation needs to focus on the following issues: to develop the use of remote sensing data and of numerical weather models; to improve the application of seasonal forecast and to evaluate the impact of extreme events on agriculture; to develop and validate agrometeorological models; to apply climate scenarios for evaluating the
impact of climate variability/change; to improve the methods of agrometeorological information dissemination; and to establish a network for agricultural meteorology.

Agriculture needs agrometeorological models to predict and forecast crop yields and productions, to support decisions, and to minimise environmental costs of agriculture with short-term consequences and outputs or inputs with long-term consequences (Marachhi, et al., 2005). The models are basically formal expressions of physiological functions fed with climatic forcing and other environmental variables.

The Tasks of Agricultural Meteorology

Agricultural meteorology is an applied, cross-cutting science. As in the case of any applied science, the basic initiators of the activity are the social and economical needs (Sivakumar, 2004). It is no doubt that the crop yield depends on the weather. If we know the relationship, we can determine an exact weather-plant growth function. Knowing any exact function, with a model, we are able to describe the soil-plant-weather (climate) system and we can predict the yield. If we can forecast not only the yield but also any other step of plant development a better product will result. The conclusion is very simple — we have to study the system. The possible questions we have to answer within the frame of agrometeorology and the scope of agricultural meteorology are:

Yield estimation, forecast:  - quantity
                           - quality
                           - date of ripening
                           - dynamics of ripening

Support of agrotechnics - planning of the cultivation
                           - irrigation forecast
                           - fertilizer application
                           - plant protection

Determination of planting zones.

The list is far from the complete because it concentrates mainly on agriculture and does not deal with the other CAgM mandated issues such as horticulture, forestry, or fishery which all have special problems. To solve these problems and to find new agrometeorological perspectives for the conservation of natural and environmental resources in harmony with agricultural production systems, it seems that there is no need to discover a new direction of agrometeorology, but only to properly restructure the knowledge collected in the last decades. To solve agrometeorological problems, we need:

Observation - phenology

Measurement - standard meteorological elements
               - special: i.e., evapotranspiration
               - special canopy climate (microclimate)
The increasing climate variability and climate change are new challenges to the entire agricultural meteorology community (Salinger, et al., 2005). In some places of the world, the main problem in agriculture is not the increase of yield but to maintain an acceptable level of production. This is the reason why traditional agrometeorology has lost its position and it should shift its activity in the direction of environmental protection. In the case of the observations for remotely sensed data use, new methods for solutions have opened up, mainly in regard to phenological observation (Van Vliet and Clevers, 2003). Agrometeorology could also have an important role in effective chemical use and environmental protection (Motha, et al., 2006). Unfortunately in some parts of the world, the lack of food has not yet been solved and the increase in yield continues to be a fundamental question. In this case, the traditional agrometeorological application has not changed from its original goals, but the conservation of nature must continue to play an important role in other areas of the world. From this point of view, it’s necessary to distinguish between the developed and less developed parts of the world. In order to give some perspective about the present socio-economic expectation towards agricultural meteorology, we will now discuss the research supported by the European Union from the point of view of the conservation of natural and environmental resources in harmony with agricultural production system.

**Agrometeorology Themes Supported by EU Framework Programmes**

The Research and Technological Development Framework Programme (RTDFP) of the European Community, the EU framework programme, was a research funding instrument developed during the 1980s following a long period of negotiations and experiments, which were subsequent to the European Council decisions in 1974 that established such activities at the community level. The measures were intended to answer the existence of the so-called technology gap of which Europe was suffering compared to its main competitors, the United States and Japan.

The establishment and development of the RTDFP coincided with the completion of the unified European market for which the final step was the Treaty of Maastricht in 1992. The first research actions under the RTDFP were initiated in 1983 and the Single European Act in 1986 was the first community legal document to set the legal grounds for community action in research. The second RTDFP was adopted following this in 1987 (as a comprehensive structure, it was in fact the first), nevertheless with individual research fields adopted separately by the European Council. Following the Treaty of Maastricht, the adoption procedure has been significantly simplified, and the multiannual programme structure covering the majority of research and technological development areas has been implemented.
Over the years the RTDFP developed into the third largest funding instrument of the European Community, nevertheless, this was small in comparison to the agricultural and structural funding. When considering the totality of spending on research in the EU, the RTDFP budget was also in the range 6 percent. These figures clearly show that the impact of community level programmes cannot be very strong. However, the RTDFP has established a practice of research and technological development policy, highlighted several structural deficiencies in technological development in the member states, and at the EU level forged a European community of researchers. The emphasis of the RTDFP was always on technological development.

The criteria which form the foundations of research funding at European level are named as “Riesenhüber criteria” after the German Ministry of Science and Technology who presided the European Council in 1983. These are conceived in the spirit of “subsidiarity,” meaning that action at the community level should only be implemented when it is clearly advantageous. As such, the criteria applied to supporting research at the EU level are:

- This research should be of such a scale, that no member state can afford to support it;
- It should create additional benefit from having been jointly performed (later developed into the principle of the European Added Value);
- Benefits from the complementarity of research done at national level;
- Contributes to the cohesion of the common market and to the drafting of unitary regulatory acts;
- Contributes to the economic and social cohesion of the European Union.

The research topics linked with agrometeorological issues have been included in research into the natural environment, environmental quality, and global change with the aim to understand the basic mechanisms of the climate and natural systems and their impact on natural resources (Györffy, 2003). The main parts of the structure were the basic processes of the current and past climate system, climate variability, and simulation of climate and prediction of climate change. These were handled separately from the impact of climate changes and other environmental factors on natural resources with the objective of assessing the major impacts on natural resources and the capacity for sustainable adaptation under changing human pressure, as well as from climate variability and change. While not directly an agrometeorological theme, we also have to mention European water resources. The international research activity in Europe towards conservation of natural and environmental resources in harmony with agricultural production system began as early as 1994.

The research tasks of the first RTDFP were in agriculture, forests, and the natural environment with the objective of studying and assessing the probable effects of climate change and other environmental changes on crops, forests, and other land ecosystems, and its consequences for land resources in Europe. It provided a basis for assessing the socio-economic impact of these consequences and for developing strategies for future management. It also prescribed and invited analysis and description of the long-term impact of climate change and other human factors on the natural environment and on the sustainability and productivity of agriculture and silviculture in Europe. The second element of the project proposals were development, validation, and application of regional mechanistic models; which described the effects of
changes to the climate and to parameters linked to the climate such as CO2 concentration on agriculture, silviculture, and natural ecosystems, taking into account other human factors. Thirdly, it mentioned development of forecasting models to assess the reaction of biodiversity to long-term environmental change; assessment of consequences of climate change in biodiversity; development of a scientific base for in situ conservation strategies; and establishment of criteria for optimizing the landscape structure with a view to preventing extinction and maintaining appropriate diversity.

Specific emphasis was on the study of the particular effects of climate change on the northern forests and on marginal ecosystems such as wetlands, tundra, and taiga in the arctic and subarctic zones, and on Mediterranean forests. The more vulnerable territories to climate change impact received concentrated interest at the beginning of the research. The integrated studies of the effects of the climate and of human factors on mountain ecosystems and establishment of links to assess socio-economic impact were handled under a different topic. The changing composition of the atmosphere, mainly ozone depletion, was separately discussed under the development of models assessing the potential impact of increased UV-B radiation on the environment (both natural and urban) and on health. The UV-B question of course is not a typical agricultural problem since it affects mainly human beings. The most important theme was the assessment of the way in which land use, through such activities as forestry, agricultural practices, urbanization, the collection and processing of waste, water drainage, concentration of specific industrial activities in coastal zones, tourism, and civil engineering projects, can influence eutrophication and the contamination of aquatic systems. Last but not least, there were issues of the modifications and rehabilitation of forest ecosystems after forest fires.

In regards to the conservation of natural and environmental resources in harmony with agricultural production systems, one of the most important themes was land resources and the threat of desertification and soil erosion in Europe. The objectives aimed to provide an integrated approach to understanding, in the context of climate change, the process of desertification and soil erosion in Europe, in the interest of reversing this process. This took into account the complexity of the system of varying interdependent factors leading to the deterioration of land resources in areas susceptible to desertification and soil erosion. Simultaneously, the most important issue was the development of the scientific foundations for rational management of land resources in certain parts of Europe, which are threatened or affected by desertification and soil erosion. With regards to climate change and the reports of WMO/United Nations Environment Programme (UNEP) Intergovernmental Panel on Climate Change (IPCC), and the predicted climate for Europe, the issue of desertification appeared to be the main challenge to European agriculture.

The most important research tasks in the context of desertification were:

- Integrated research to assess qualitatively and quantitatively the relative roles of the various processes involved in desertification and soil erosion: climatic, hydrological, biological and soil-related;
- Modelling of the complex dynamics of the various processes concerned, on different spatial and temporal scales, in systems which are desertified or susceptible to
desertification or soil erosion, including their repercussions on the climate, so as to predict the future course of the phenomenon;

- Setting-up of suitable sets of data with which to detect any change and validate models; identification of indications of potential desertification and soil erosion;
- Development and improvement of countermeasures and strategies to control and reduce the deterioration of land resources in areas susceptible to desertification and soil erosion, including assessment of essential technological intervention.

There were 15 projects accepted under the “Agriculture, forests and the natural environment” during the life-span of the first Research and Biotechnological Development Framework Programme (RTDFP), out of which three were more related to the natural environment (Ghazi, et al., 1997).

The projects could be grouped under the conservation of natural and environmental resources in harmony with the agricultural production system:

- Climate change experiment with the objective of studying the response of entire catchments to increased CO2 and temperature;
- Predicted Impacts of Rising Carbon Dioxide and Temperature on Forests in Europe at stand scale;
- Long-term carbon dioxide and water vapour fluxes of European forests and interactions with the climate system;
- Forest response to environmental stress at timberlines;
- Spatial modelling at the regional scale of the response and adaptation of soils and land use systems to climate change;
- Climate change, climatic variability and agriculture in Europe: an integrated assessment;
- Improving wheat model accuracy and suitability for regional impact assessment to develop a new model for assessing the impact of environmental change on European wheat production to predict the impact of climate change at the regional-scale, which places particular emphasis on the ability to predict increasing CO2 concentration across diverse sites;
- Changing climate and potential impacts on potato yield and quality;
- Managing European grasslands as a sustainable resource in a changing climate to investigate the long-term responses of a representative selection of European semi-natural grassland ecosystems to elevated CO2 and climate change across a European transect which exploits the natural gradients in environmental variables;
- Carbon and water fluxes of Mediterranean forests and impacts of land use/cover changes;
- Long-term regional effects of climate change on European forests: Impact assessment and consequences for carbon budgets;
- Model evaluation of experimental variability to improve the predictability of crop yields under climate change.

In the framework of “Land resources and the threat of desertification and soil erosion in Europe,” 22 projects were supported, namely:
• An integrated approach to assess and monitor desertification processes in the Mediterranean basin. Using an integration of ecological models and information from operational earth observation and meteorological satellites to assess and monitor regional scale indicators of sensitivity to desertification;
• Characterisation of the aridity processes on Mediterranean Europe. Protection and management guidelines;
• Policy-relevant models of the natural and anthropogenic dynamics of degradation and desertification and their spatio-temporal manifestations of southern Europe;
• An integrated methodology for projecting the impact of climate change and human activity on soil erosion and ecosystem degradation in the Mediterranean: a climatic gradient and dynamic systems approach;
• Concerted Action on desertification and its relevance to contemporary environmental problems in the Mediterranean;
• An integrated approach for sustainable management of irrigated lands susceptible to degradation/desertification which would develop and validate management-oriented models accounting for bypass flow that may increase hazard of salinization of subsoil and groundwater, significantly decreasing efficiency of salt-leaching and crop yield;
• Modelling Mediterranean Ecosystem Dynamics which would undertake computer based simulation modelling of plant community dynamics;
• Restoration of degraded ecosystems in Mediterranean regions;
• Synthesis of change detection parameters into a land-surface change indicator for long-term desertification studies;
• Consequences for the mitigation of desertification of EU policies affecting forestry activity: a combined socio-economic and physical environmental approach (Focuses on the hydrological and soil degradation consequences of various EU Policies and Funds including the 1992 Common Agricultural Policy (CAP) reforms relating to aforestation of agricultural land which impact on forestry activity);
• Modelling within storm dynamics on soil erosion;
• A spatial modelling tool for integrated environmental decision-making in the northern Mediterranean region;
• Relating research and policy in formulating and implementing environmental policies for combating land degradation and desertification in the Mediterranean basin;
• Modelling the effect of land degradation on climate;
• Mediterranean desertification and land use that would consolidate fundamental areas of research, field investigations and modelling that are necessary for quantifying and understanding desertification processes at selected sites across southern Europe;
• Mediterranean desertification and land use that would apply and integrate the existing knowledge, obtained in the different Mediterranean Desertification and Land Use (MEDALUS) projects in targeted areas along the northern Mediterranean that are already desertified or threatened by desertification at regional scale;
• Mediterranean desertification and land use that would develop a set of regional indicators which provide a planning tool for application to desertification at regional, national and European scales;
• Mediterranean desertification and land use that would improve the understanding of the impact of desertification on headwater channels and rivers, where desertification is understood to include the effects of both human activities and climatic changes;
• Modelling vegetation dynamics and degradation in Mediterranean ecosystems;
• Remote sensing of Mediterranean desertification and environmental changes;
• Wind erosion on European light soils;
• Wind erosion and loss of soil nutrients in semi-arid Spain.

The Agrometeorological-Related Proposals of the 5th RTDFP

The 5th RTDFP featured a new approach in structuring European research funding in trying to achieve a better integration of research fields (Ghazi, et al., 1997). The programme was based on the major elements of the 4th Framework Programme, however, the links among different parts were supposed to be more organic. Research topics linked with agrometeorology have been considered again from their environmental aspect, and classified as such into the Energy, Environment and Sustainable Development part of the programme. The programme on “energy, environment and sustainable development” centred around six key actions: sustainable management and quality of water; global change, climate and biodiversity; sustainable marine ecosystems; the city of tomorrow and cultural heritage; cleaner energy systems, including renewable; economic and efficient energy for a competitive Europe; as well as generic activities, and Research and Technological Development (RTD) infrastructure and facilities. The strategic goal of this part of the programme was to promote environmental science and technology so as to improve our quality of life and boost growth, competitiveness and employment, while meeting the need for sustainable management of resources and protection of the environment in line with the goals and objectives of the fifth action programme on the environment. The results were supposed to provide the basis for policies formulated at community level relating to the environment or deriving from international environmental commitments in particular, the implementation of the Kyoto Protocol requiring urgent support for RTD on a number of issues.

Issues of interest from agro-meteorological point of view were tackled in “Key Action 2: Global Change, Climate and Biodiversity.” The aim of this key action was to develop the scientific, technological and socio-economic basis and tools necessary for the study and understanding of changes in the environment. Aiming for an integrated approach, the priorities were:

• To understand, detect, assess and predict global change processes with the aim to focus on mainly on European and subregional causes and impacts of specific global change problems, such as climate change, ozone depletion, biodiversity loss, loss of fertile land and habitats, disruptions to ocean circulation;
• To foster better understanding of terrestrial (including freshwater) and marine ecosystems and their interactions with emphasis on interactions with land surfaces and land use, soil, water, atmosphere and ocean; role of biodiversity and climate change; interactions between ecosystems, biogeochemical cycles, large-scale land degradation and desertification;
• Scenarios and strategies for responding to global issues with the aim to provide a sound scientific basis for the development of tangible management strategies and actions to address the adverse consequences outlined in the key action;
European component of the global observing systems with the aim to identify and fill key gaps in existing observation system capacity in order to ensure that the necessary data are available to address the prediction, impact assessment and response options to global change.

Out of 267 projects funded, only 22 were linked with agrometeorological issues:

- Assessing climate change effects on land use and ecosystems: from regional analysis to the European scale;
- Biodiversity and economics for conservation;
- Scenarios for reconciling biodiversity conservation with declining agricultural use in the mountains of Europe;
- Biodiversity in herbaceous semi-natural ecosystems under stress by global change components;
- Age-related dynamics of carbon exchange in European forests. Integrating net ecosystem productivity in space and time;
- An investigation on carbon and energy exchanges of terrestrial ecosystems in Europe;
- Effects of land-use changes on sources, sinks and fluxes of carbon in European mountain areas;
- Securing gene conservation, adaptive breeding potential and utilisation of a chestnut tree (Castanea-sativa Mill.) model in a dynamic environment;
- Conservation of soil organism diversity under global change;
- European phenological network - a network for increasing efficiency, added value and use of phenological monitoring, research, and data in Europe;
- Exploitation of aphid monitoring systems in Europe to improve observation and prediction of global change impacts on terrestrial ecosystems;
- Forest carbon - nitrogen trajectories;
- Sources and sinks of green-house gases from managed European grasslands and mitigation scenarios.
- European Forum on Integrated Environmental Assessment;
- Modelling the impact of climate extremes;
- Greenhouse gas mitigation for organic and conventional dairy production;
- Multifunctional landscapes: towards an analytical framework for sustainability assessment of agriculture and forestry in Europe;
- Development of operational monitoring system for European glacial areas - synthesis of earth observation data of the present, past and future;
- Phenological observations and satellite data Normalized Difference Vegetation Index (NDVI): trends in the vegetation cycle in Europe;
- Predictability and variability of monsoons, and the agricultural and hydrological impacts of climate change;
- Regional assessment and modelling of the carbon balance within Europe.
The Results of the Research

The results obtained within the work performed in the projects show that atmospheric concentrations of greenhouse gases are increasing leading to an expected warming while regional aerosol loading increases are expected to have net cooling effect (Ghazi, et al., 1997). These changes are mainly due to fossil fuel combustion and other industrial processes, agriculture and land-use/land-cover changes whose combined effect is expected to alter the climate on European and global scale affecting the temperature, soil moisture, precipitation, sea level and ecosystems. In terms of hydrological regimes and water resources in Europe the implementation of climate change scenarios belonging to different time horizons allows a better estimation of the vulnerability of river-based dependent activities such as inland navigation, drinking water supply, irrigation and tourism with implications for tourism and agricultural production. Ongoing research projects provide a strong, rigorous methodological basis for estimating how forests will be affected by rising atmospheric concentration of carbon dioxide and change in other climatic parameters, and how forests will influence regional carbon, water and energy fluxes. There is also a growing realisation at several levels of the need to recognise formally and to provide actions against the deeply embedded but growing problem of desertification in European countries, especially those of the Mediterranean. The extensive research also carried out within the framework programmes addressed the questions of what actions are needed, where and by what means, to mitigate the impact of desertification in Europe and what technical issues have to be resolved from scientific, political, social and economic perspectives.

Since the 1950s there have been major changes in land use, which are supplemented by prospects of climate with evidence that this will hinder rather than help the progress towards sustaining water supplies and agricultural productivity. Drier winter conditions are the largest potential problem, but much depends on the changes in rainfall patterns for which there is as yet no reliable predictive methodology. There is also evidence of decreasing rainfall in the Mediterranean basin a trend for which is not possible to establish whether it is due to global warming or simply to natural decadal time-scale variability. A complex blend of geographical, social, economic and scientific information combined with carefully developed policy and the instruments to implement that policy are required by mitigation strategies.

The frequency of occurrence of agriculturally significant extreme events is strongly altered by relatively small changes in climate. Among the extreme factors analysed were crop-specific high-temperature thresholds, length of frost-free periods, understanding and the effects of CO2 and temperature on crop yield. Simulations of crop responses to current and possible future environmental conditions have improved. Current differences in crop productivity between northern and southern Europe are likely to increase under climate change. The inter-annual variability of yields is particularly sensitive to changes in climatic variability. Climate change and land use changes will therefore be an important aspect to consider in the future, in particular, in relation with land management and spatial planning. In parallel, the progress in forecasting inter-annual and seasonal variations of European climate will, among other benefits, help to maintain agricultural productivity.
Conclusions

In the summarising the research activity of the European Union, we can state that the agrometeorological activity, including research, development, and application has not disappeared, only its national, mainly national meteorological service level presence has moved into wider and sometimes hidden platform. They have achieved results in the effective conservation and management of natural and environmental resources. They have been impacted by climate variability, climate change, increasing energy costs, environmental regulations, changing demographics, and access to appropriate technologies. There is no change that developing better modelling and forecasting tools to provide users with greater flexibility in decision making is significant both for the scientific issues involved as well as for the practical relevance of the results. The impact of weather and climate on conservation and management of natural and environmental resources is increasingly viewed in the context of risk management. Land degradation, water resource management, drought, and fire are the main topics that agrometeorologists need to focus on in the future. The increasing tendency of weather extremes and natural disasters as consequence of climate change, combined with explosive population growth, seriously challenge the future quality of life for all, therefore effective coping strategies for natural disasters are essential.

The major agrometeorological themes in managing natural resources for sustainable agricultural development include: preparedness (best practices), monitoring (data), assessment (vulnerabilities), mitigation, and adaptation. Good stewardship of the land is essential for sustainable agriculture. There is a growing recognition that land degradation is a major worldwide issue and there is a need for more complete evaluation of the expansion of degraded land around the world.

It is still essential that provision of adequate and appropriate weather and climate information from the meteorological observation networks to users on a near real-time basis is especially needed for developing risk management strategies to cope with climate variability and climate change. The idea that many national meteorological services should produce income mainly from the data or service information is not valid in many countries. As consequence of the commercial activity, there is some conflict between the agrometeorological research and data suppliers. Of course to integrate station, gridded, and remotely sensed data in order to improve model accuracy and provide more useful products is primary expectation from both sides. We have to stress that the use of remotely sensed data has rapidly grown among the data resources. The commercial conflict partly could be solved using a free accessible satellite data. Placing high priority on free and open access among disciplines for data, results, findings and management would succeed to increase cost effectiveness but currently that seems to remain the dream of scientists. To disseminate rapidly time sensitive information regarding meteorological phenomena and its application for land resource management would be a very effective way for the conservation of natural and environmental resources in harmony with agricultural production systems.

In this context, greater emphasis should put on the quantification of natural and environmental resources by developing and providing access to hydrological, meteorological and geographical databases and environmental impacts. A long-term perspective of resource use for sustainable
Agricultural development should be promoted rather than short term measures since there is a finite capacity of natural resources and the environment, especially under changing demographics.

The agrometeorological activity can provide assistance to current strategies for conservation and management of natural resources and incorporate preparedness and mitigation plans to effectively cope with the increasing frequency of extreme events and natural disasters and their impacts on agriculture. It should be ensured that risk and vulnerability assessments are carried out at an appropriate scale and incorporate socio-economic factors along with the agrometeorological analysis. Analyses of economic values of the information products and services should be provided by the agro-meteorology community.

We should promote the use of an integrated risk management framework that takes into account preparedness, monitoring, assessment, mitigation, and adaptation and encourage the development of robust models that provide probability based results. We have to re-emphasize the current agriculture zoning and practices in response to climate variability and change. Among others it is an ancient agrometeorological theme that should be re-evaluated. It is essential to support the decision makers with information tailored to their needs through rapid dissemination such as internet-based, early warning, and decision support systems that also include geographic information. Maybe it is not the basic job of agrometeorologists but they should maintain some kind of feedback mechanisms constantly evaluated and updated.

Finally we have to mention the importance of education and training mainly in the less developed area of the world and in which the WMO can give great help to its members. We have to increase the outreach and education regarding the impacts of climate variability and weather extremes on land conservation while recognizing the need for that land to support an ever-increasing population.

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**References**


The Australian National Agricultural Monitoring System – A National Climate Risk Management Application

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Abstract
Climate variability exposes agricultural producers to considerable risks because the outcomes of their decisions cannot always be confidently predicted. Historically, agrometeorological information has been used by managers of production systems to make farming systems somewhat resilient to variable climates. However, this information is often not available to producers in a form that they can readily access and use in their production systems. This paper describes the National Agricultural Monitoring System (NAMS), an Australian tool being developed to bring together historical and current: information on historical climate variability; contextual factors such as land use and soil type; the impact of climatic variation on a variety of agricultural production systems at a regional level; and economic information on agricultural production system performance. The impetus to develop this tool came from a need to provide support to the Australian government’s drought mitigation programs. However, the added potential of this tool to provide real-time climatic and production information to producers was recognised early by a decision to make the information freely available via a Web site. It is envisioned that producers will be able to use the information provided by NAMS to assist in their management decisions, by being better able to judge and assess the risks to production systems posed by climate variability. The development of NAMS has involved extensive collaboration with major stakeholder groups, which has helped ensure that the tool has strong support from its key users and is a valuable tool for individuals outside of its target audience.

Introduction
Agricultural production systems are diverse and include cropping systems, pastoral systems, and mixed farm enterprises. While the systems are diverse, a commonality between them is the need to manage financial, environmental, and social risk. Typically, the management focus is both on a short- and long-term basis: production and profitability are in the simplest sense the short-term management focus; however, management decisions are made within the context of resource conservation, economic, political, and lifestyle influences (Blacket, 1996; Hammer, 2000). An additional major risk factor that affects the biophysical, socio-economic, and political systems is climate variability (Hammer, 2000). Climate variability exposes decisionmakers to considerable risk because outcomes of decisions cannot be confidently predicted, such as: crop rotation decisions, marketing strategies; infrastructure investment; and policy decisions that affect ecosystem management.

Historically, agrometeorological information has been utilised by managers of production systems to make farming systems somewhat resilient to variable climates (Meinke and Stone, 2005; Steffen et al., 2006). For example in many regions of the world, fallows have been
adopted for capture and storage of soil water for the following season’s crop to insure against the possibility of low, in-crop rainfall (Lyon et al., 2004; Meinke and Stone, 2005); summer cropping is generally not practiced in regions with unreliable summer rainfall such as southern Australia, the Pacific Northwest of the United States, and Mediterranean regions; and conservation tillage practices have been developed partly by the need for water retention in dry areas (Lyon et al., 2004). However, these systems are not necessarily optimally adapted for climate variability, for example, farming systems developed during a run of wet seasons may not be as resilient during a run of dry seasons (Meinke and Hammer, 1995). In addition, the changes in extremes expected to result from climate change, and already observed in some regions of Australia, are unlikely to be adapted for in current production systems.

Although it is well understood that a thorough knowledge of historical climate variability is an invaluable tool in helping producers manage associated production risks, this information is often not available to producers in a form that they can readily access and use in their production systems. This problem has been recognised by information providers and there are numerous current examples of climatic information being made available, particularly through the internet (e.g., http://www.bom.gov.au/; http://www.metservice.co.nz). However, the scope of this information is often limited by the mandate or interests of the group providing the information. For example, the Australian Bureau of Meteorology (BOM) provides a vast array of climatic information and data but does not provide an agricultural context to this information. Similarly, an agricultural research group may provide information about a specific tool that uses historical climatic information but does not place the tool, or the climatic information used in the tool, in a broader historical context.

**Background**

**Impacts of Climate**

Australian agriculture operates in a highly unreliable climate (Laughlin and Clark, 2000; Stone and de Hoedt, 2000), which is characterised by frequent floods and intense, widespread droughts. These climatic extremes affect all types of agricultural production and represent a challenge that farmers must manage in order to remain viable. There is a well-established relationship between El Niño events and drought in Australia, although not all drought events are El Niño related. El Niño events generally occur every 2-7 years (Cane, 2000; Meinke and Stone, 2005). El Niño events typically, but not always, result in severely reduced rainfall in winter and spring, particularly across eastern Australia; where the majority of high-value cropping and livestock husbandry is practiced. Despite the challenges of farming in Australia, agricultural activities cover about 60 percent of the continent, much of it in the dry, semi-arid rangeland regions.

**Managing the Risk of Drought**

Before 1992, the Australian government did not have an explicit drought policy; assistance to affected producers was provided through a natural disaster relief program. In 1992 a national drought policy was established. This policy shifted the emphasis away from drought being classified as a natural disaster and towards that of a normal component of the operating environment. Drought, and more broadly, climate variability, was seen as an inherent business
risk that producers needed to manage as they would any other potential risk. This shift in thinking was intended to create a setting in which drought was considered a normal part of the Australian farming environment; the core principle to encourage producers to adopt self-reliant approaches for managing climatic variability and to prepare for drought. While acknowledging the principles of self-reliance, the National Drought Policy (1992) also recognised that there would be circumstances that were beyond the ability of farmers to manage alone. In these so called “exceptional circumstances,” governments could provide assistance to support otherwise viable farm enterprises through periods of “severe downturns” in income.

**Drought Assistance**

Since the 1992 National Drought policy was enacted, it has been reviewed and its principles reinforced several times; however, the Exceptional Circumstances (EC) component has changed in relation to its criteria and implementation. The current criteria for EC events are: the event must be rare and severe and of a scale to affect a significant proportion of farm businesses in the region; the event must result in a severe impact on farm production and income that lasts for at least 12 months as a result of the event, and that the downturn in income is not a result of other issues such as competition from international markets; and that the event must not be predictable or part of a process of structural adjustment. Rare events are considered to be those that occur on average once every 20 – 25 years; and the event is severe if it lasts for a period greater than 12 months. The framework for assessment of EC revolves around the assessment of: meteorological conditions; agronomic and stock conditions; water supplies; and environmental impacts. Although most commonly enacted as a result of a rare and severe drought, EC events may include a combination of events such as drought and frost. Key to the process of decisionmaking is the involvement of an independent advisory council comprising agribusiness professionals.

Once a region has received an EC declaration, farmers within it are eligible to apply for a range of assistance measures. However, before assessing these assistance measures, farmers still need to demonstrate that they operate a long-term viable enterprise and must also pass income and assets tests. Farmers in EC-declared areas may apply for income support, equivalent to the unemployment benefit, and business support, in the form of interest rate subsidies on operating costs from the federal government. EC assistance lasts for up to 2 years, but regions can be assessed for extension of support before their 2-year period expires if adverse conditions continue. Other concessions and support are available from the state and territory governments in certain circumstances; however, they are not considered here due to their varying nature from jurisdiction to jurisdiction.

**The 2002 – 2003 Drought**

Australia has recently experienced one of its most severe droughts on record. The most severe part of this drought, in terms of geographic extent and rainfall deficit, occurred between March 2002 and January 2003, and covered most of the agriculturally productive regions in the country. Indeed, the most important agricultural regions generally experienced conditions at least equivalent to a 1 in 20-25 year event, with a number of regions recording their lowest rainfall on record. Not only did the 2002-2003 drought significantly reduce farm production during the
event but ongoing effects continue to be felt in many regions. For example, the irrigation industries rely on major reservoirs and many of these, as of 2006, had still not returned to pre-drought levels. The major reservoirs in the Murray Darling Basin, Australia’s most important irrigation region, fell to 17 percent of capacity in 2003, and 3 years later are still below levels recorded before the drought. As a result of this shortfall in stored water, irrigators are continuing to experience restricted volumes.

The recent drought led to over 90 applications for EC funding, and just under 50 percent of Australian agricultural land received some level of support. In addition, due to the persistence of the drought, additional measures were developed to provide ongoing support for regions that had clearly not recovered from the impacts of the drought after their initial 2 years of support ended.

A major national drought workshop was held to discuss the efficiency of the current measures in dealing with drought, and to map out new and improved ways to deliver drought assistance. One of the issues raised was that the current system of applying for support was complex and time consuming and often led to support being provided well after the worst impacts of the drought had been experienced. Partly as a result of this feedback, the Australian, State, and Territory Agricultural Ministers, through the Primary Industries Ministerial Council (PIMC), gave consideration to the development of a national agricultural production monitoring system to assist in the development of EC applications and to facilitate decisionmaking for government intervention. It was envisaged that such a system would provide an agreed set of data for use by both the applicants and assessors, and for this data to be readily available via the Web.

**The National Agricultural Monitoring System**

The rationale behind developing the NAMS was to automate the creation of an EC report via the Web. The automation was intended to streamline the application and assessment processes for EC, and reduce the time and cost associated with the process. It was envisaged that NAMS would also provide up-to-date climatic and production information that could help target regions that may be coming into drought; and also provide climatic and production information that could be utilised by producers to better prepare for, and manage, drought.

To simplify and streamline the existing EC application process, the NAMS Web site was designed to produce reports that provide a complete set of contextual, climatic, production, and economic analyses. From this base, it was intended that state and territorial governments add their own interpretive text and additional supporting information to the provided analyses. One of the potential strengths of this approach is that the analyses will be standardised between all applications, yet the applicant will still be able to provide additional contextual and interpretive information.

NAMS was tailored to produce EC reports for regions, but was also designed to produce state and national agricultural and climatic reports. These reports will be updated monthly and are intended to provide a snapshot of current conditions, primarily to highlight regions where conditions are deteriorating due to adverse climatic conditions. This early alert system could be used to target support to regions before the primary impact of the drought is experienced, thus reducing the social, environmental, and economic impacts.
Although NAMS was initially conceived to assist the Australian government in the delivery of drought policy, it was envisaged that the majority of users would be the general public. NAMS will be a public Web site where people can run any of the available analyses for their region of interest. This open access will make NAMS a valuable resource not only for agricultural producers but also for a wide range of land managers, including such groups as local governments, water catchment authorities, and local land-care groups.

In the past many stakeholders viewed the analyses undertaken in the EC assessment process as something of a “black box” and as a result did not always accept the rationale or methods used in the process. Loss of trust between stakeholders can impede the flow of information, increase inefficiencies, and possibly lead to more uncertainty in final decisions (Laughlin and Clark, 2000). To circumvent this problem, NAMS, with the participation of state and territorial agencies, provides free access to data that are used both in the EC application and assessment processes. Data and analyses included in the NAMS were chosen by a scientific advisory committee, established with members from major stakeholder groups, including state and territorial governments and key Australian research agencies. The intention of having such a comprehensive advisory group was to maintain transparency in the system and to ensure that trust was maintained with the stakeholders.

As previously stated, in order to receive EC funding, an EC application must show that a region has experienced a severe downturn in production and income as a result of a climatic event that would only be expected to occur once every 20 to 25 years. In order to establish if a region has experienced such an event the analyses used must put the “event” into a historical perspective. This underlying principle guided the choice of analyses included in NAMS. The description below is limited to a sub-set of the analyses contained within the EC report. Further details of the analyses used in NAMS are available from the Web site at www.nams.gov.au.

**Regional Context**

This section of the EC report is designed to provide a detailed overview of the regions biophysical and climatic characteristics. Maps are provided showing relevant layers such as land use, soil type, and water holding capacity. These maps are accompanied by tables containing information on the major farm industries and the number of farm enterprises within a region. Detailed climatic information is also provided for the EC region showing average rainfall and temperature, rainfall reliability, and the growing seasons. Figure 1 shows an example of how average rainfall is displayed for an application region. This figure shows spatially how rainfall varies across the application region and it also puts the region into the broader context by displaying it against the whole of Australia.
Climate

Average rainfall

Average annual rainfall

The following figure shows a summary of average annual rainfall for Australia and for the EC report region.

Figure 1. Average annual rainfall output generated from the NAMS as part of the EC report.

When trying to assess the impact of a climatic event on production it is important to understand the relevant growing seasons for each region. Figure 2 was created using a simple growth model called GROWEST (Fitzpatrick and Nix, 1970) to characterise the growing season for a site. This simple model uses light, temperature, and moisture input data. The figure can be used to help define the normal growing season of the pastures within the region, i.e., for cool season (C3) or warm season (C4) pastures. In this figure zero suggests no growth potential and one suggests optimal weather conditions for growth. This model also includes some soil characteristics, although it is largely weather driven.
Figure 2. Potential growing season output generated from the NAMS as part of the EC report.

**Meteorological Event Analysis**

The “Event Analysis” section is designed to place the drought event within a historical context. To do this, NAMS uses a range of point-based and spatial analyses based on data provided by the Australian Bureau of Meteorology. To achieve this, percentiles are used throughout the rainfall analysis section and for other variables also. Percentiles are merely a way of ranking data, be it temperature, growth or rainfall, on a 0-100 scale. By conversion 0 is the lowest, 50 the middle, and 100 the highest in any particular series.

Analyses are provided not only for a specified “event period” but also for a range of agronomically relevant periods — a strategy designed to examine “effective rainfall.” The importance of assessing “effective rainfall” rather than aggregate rainfall can be highlighted by the observation that reasonable production can be achieved in a drought year if the rain falls at the right times for production. For example, there have been instances where a 5th percentile event was apparent at an 18-month time scale while the important agronomic production season (e.g., spring) within this 18-month period was at the 60th percentile.

The spatial analyses used in NAMS show the extent of rainfall during a range of periods. These include user-defined periods, growing seasons, and calendar seasons within the specified period. Spatial rainfall analyses are based on historical monthly rainfall data provided in approximately 25 x 25 kilometer (km) grid format. Due to the relatively coarse spatial resolution, the use of this tool is limited in areas of low-station density and around tall and narrow mountain ranges. In some areas the grids are also slightly less reliable during summer months due to the patchier and heavier rainfall.
Point-based rainfall analyses are used to develop a better understanding of “effective rainfall;” and how the rain actually fell over the recent past. When developing a report for a region one or several rainfall stations can be selected for detailed analyses. In Australia, climate data are recorded daily at more than 7,000 sites spread across the country. However, for most of these sites a complete data set that contains continuous measurements from 1900 to present is not available. This may be due to maintenance work, instrument failure or for a range of reasons related to the observation network historically being supported largely by volunteers. For the rainfall station analyses within NAMS there is a default that only allows stations with at least 30 years of measured data to be used.

The point-based analyses used in NAMS include a 12-month moving average of rainfall using data from 1900, and bar graphs of monthly and weekly rainfall extending back 5 years. The moving average helps place the current event into a historical perspective by allowing a quick visual assessment of how severe the worst 12-month period of current drought was compared to all other 12-month rainfall periods. The bar graphs of actual rainfall provide a picture of when the rain actually fell, which combined with knowledge of the agronomic system, can provide insights into rainfall effectiveness.

**Impact on Production Systems**

A region may experience a climatic drought without necessarily experiencing an impact on agricultural production. For example, well below-average seasonal rainfall may have occurred but the timing of the rainfall could have been conducive to pasture growth. Alternately, particular industries may be able to compensate for the lack of rainfall by purchasing fodder or using irrigation water. Therefore, a region needs to establish that it has not only experienced a meteorological drought but that it has also experienced a severe downturn in production as a result of the drought and not some other factor such as product prices or poor management. As in the previous section, the “Impact on Production Systems” section of the EC report places the impact of the current event into an historical perspective. Analyses in this section focus mostly on modelled production outputs and typically use at least 100 years of data for comparisons. The production-based analyses currently used include: pasture growth, both temporal and spatial; cropping models for the main summer and winter crops; and, Normalised Difference Vegetation Index (NDVI), which is a satellite-derived measure of relative “greenness.” The value of models is that they allow the end user to see the impacts of the various factors — individually or collectively — on growth. These models are especially useful for assessing rainfall effectiveness. A range of actual data is also used to show historical production levels for a region for crops and livestock.

Plant growth models can also be used to help assess the impact of climate variability on pasture and crop production. AussieGRASS (Carter et al., 2000) and GROWEST are two models commonly used for pasture growth assessments in Australia. AussieGRASS is a detailed growth model that includes the effects of climate, soil, and agronomic practices on growth whereas GROWEST is a simple point-based model of growth potential. Normalised Difference Vegetation Index (NDVI) is based on data collected from satellites, and shows the level of photosynthetic activity (or greeness) within plants, and, as a result, can be used to infer rainfall
effectiveness. A limitation of the NDVI model is that data are only available from 1991, and thus does not provide a good historical comparison.

Spatial and temporal comparisons are provided for each of the techniques listed above. For example, Figure 3 shows accumulated weekly potential pasture growth for the C3 plant type over the last 3 years using the GROWEST model. In this figure the horizontal axis is time and the vertical axis is the index of potential growth. Grey lines represent the 3 years of modelled data. The median is represented by the thick black line; and the percentile ranges (30th to 70th and 5th to 95th) are also represented by the grey-shaded areas. There are two components to interpretation: 1) the accumulated value of growth potential to any point in the year; and, 2) the instantaneous growth potential. An alternate way to look at potential pasture growth is to use a spatial growth model such as the AussieGRASS model.

![Figure 3. Accumulated potential pasture growth for C3 mesotherms generated from the NAMS as part of the EC report.](image-url)
**Economic Information**

Economic information is provided to gain a fuller understanding of the impacts of a drought. Economic information is important because rainfall and production figures alone can mask on-farm impacts of a climatic event. For example, livestock production may not necessarily decline during a drought because producers purchased additional fodder to keep stock in prime condition. As result, production might remain stable but profits declined.

NAMS captures this information using a number of economic indicators. The indicators used are: farm financial performance; farm revenue; farm cash costs; and farm debt. The data for these analyses is compiled using an ongoing farm survey program run by the Australian Bureau of Agricultural and Resource Economics. Farm cash income is the primary measure and is used to track farm profits over the last 15 years. Farm cash income is a measure of cash flow while farm business profit is a more accurate measure of economic performance. Farm business profit includes all cash receipts and costs (i.e., farm cash income) plus non-cash items like changes in trading stocks, depreciation and an imputed family labor cost. Analysis of economic data helps answer questions about farm viability and short-to-medium term prospects. More importantly, provision of economic data allows the link between the climatic event and the farm profits to be established.

**Conclusions**

The NAMS evolved out of a need to streamline the Australian government’s drought assistance program but is developing into a broader tool. NAMS has been designed to deliver a number of set products, including EC reports, but also has the capacity to deliver a wide range of climatic- and production-based analyses for any selected region within Australia. Analyses are done both at points and spatially. The analyses selected for use in NAMS were chosen by a scientific steering group, which includes representatives of the major stakeholders. The development of NAMS has involved extensive collaboration with major stakeholder groups, including representatives from the Australian and state and territorial governments, producer groups, and scientific research organisations. The extensive consultation process has helped ensure that the tool has strong support from its key users and that it is a valuable and relevant tool for individuals outside of its target audience.

NAMS also opens up the possibility of providing proactive support to producers before the full impact of a major drought is experienced. This type of assistance could help avert significant environmental damage by helping producers prepare for, and manage, the inevitable impact of droughts. The information provided by NAMS could also help producers better manage climate variability as a business risk. Droughts are a recurring theme throughout Australian agriculture and managing droughts better will improve the long-term sustainability of farming enterprises. It is ultimately hoped that the NAMS tool will be widely used by agricultural producers to help manage climate variability by providing relevant and up-to-date information on historical, current, and emerging climatic and agricultural conditions.

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Examples of Using Agrometeorology for Management of Natural Resources
Recent Analysis and Improvements of the Statistical Water Supply Forecasts for the Upper Klamath Basin, Oregon, and California, USA

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Abstract

Upper Klamath Basin water supplies in Oregon and California, USA, have been the focus of many competing uses and needs for the past one hundred years. Water supplies have been forecasted in the basin since the 1930s based on the relationship of streamflow with the seasonal snowpack and climate. In 2001, the 5th driest year on record, agricultural irrigation was curtailed in much of the basin, with the little available water allocated to support the survival of endangered and threatened fish. The lack of available irrigation water generated a large outcry in the local and national agricultural community, prompting collaborative research beginning in 2003 to improve the accuracy of the water supply forecasts, which would enhance water management decision-making in the watershed. The focus of the research described in the present paper was to review the current statistical forecasting techniques and investigate other statistical techniques as well as research additional data variables to use in the water supply prediction models.

Introduction

USDA Natural Resources Conservation Service (NRCS) has been forecasting water supplies in the Klamath Basin since the 1930s. The NRCS forecasts water supplies at over 700 other stream gauge stations and reservoir inflow points throughout the western United States. The relationship between winter snowpacks and the resulting spring runoff spawned the development of statistically based water supply forecast methods beginning in the early 1900s. Water supply forecasts for the western United States have been traditionally requested and used by federal, state, and local water managers for flood control, irrigation, hydropower generation, and municipal use. Water supply forecast use has expanded significantly in the last decade to include fish and wildlife management and winter and summer recreation.

Most irrigation water in the Klamath Basin is allocated and delivered by the U.S. Bureau of Reclamation (BOR), which operates three reservoirs in the basin (Upper Klamath Lake, Clear Lake, and Gerber Reservoir). The BOR supplies water to irrigate approximately 810 km², which varies annually (Risley, et al., 2005).

In the 1990s, the U.S. Fish and Wildlife Service (USFWS) designated two Upper Klamath Basin fish species endangered: Lost River Sucker (*Deltistes luxatus*) and Short Nose Sucker (*Chasmistes brevirostris*). The Coho salmon in the Klamath River was also listed as threatened by the National Oceanic and Atmospheric Administration (NOAA) Fisheries Service. Water management plans were developed to provide the appropriate amount of water to improve these fish populations.
In 2001, the 5th driest year on record (based on data from 1901-2006), a very limited supply of water was available for irrigation, power, and endangered fish needs. Based on the April 2001 water supply forecast, the BOR determined that to comply with the Endangered Species Act, no irrigation water would be allocated to the farmers in the BOR Project, though other farmers in the area were able to irrigate. This decision caused many protests throughout the local, state, and national agricultural community and received the attention of the White House and the President of the United States. The resulting legislation provided some federal funds to enhance and conserve water supplies in the basin. The immediate actions included emergency well drilling, water conservation as well as long-term projects such as irrigation efficiency improvements and vegetation management. There was also funding to support improvements in water supply predictions, the basis for water conservation and management decisions. These improvements include additional data collection stations, hydrologic model development, and a study of the accuracy of the statistical water supply forecasts and ways to improve them. There is also a continuing effort to educate the water managers and the public on the use and limitations of water supply forecasts.

**Geography**

The Upper Klamath Basin encompasses approximately 20,720 km² and is located in south-central Oregon and northeastern California. The Klamath River originates at Upper Klamath Lake in Oregon and flows in a southwesterly direction, draining the Cascade Mountain Range on the west and smaller mountains on the north and east sides of the basins, and discharges to the Pacific Ocean. The Oregon part of the basin is approximately 14,500 km² (Lea and Pasteris, 2004).

**Data Network**

The Klamath Basin data collection network used to generate water supply forecasts is distributed throughout the mountainous areas of the basin as shown in Figure 1. The primary source for the climate and snowpack data used for water supply forecasting is the SNOw TELeometry (SNOTEL) network operated by the NRCS. In the Klamath Basin, the SNOTEL network consists of 19 remote stations that collect hourly precipitation, snow water equivalent (SWE), snow depth, and temperature data. Six SNOTEL sites have been augmented to provide soil moisture and soil temperature measurements at five different soil depths, and four of these sites also measure solar radiation, wind, and relative humidity.

In addition, six manually measured snow courses provide SWE and snow depth data once a month, during January through June. A snow course is a permanent site where these manual snow measurements are taken by trained observers near the first of the month during the winter and spring. Generally, the courses are about 1,000-feet long and are situated in small meadows protected from the wind. The observers take measurements along a set transect at regular intervals, averaging the measurements over the course. There are also four aerial markers in the basin consisting of poles with crossbars that indicate snow depth, which are read from a small airplane once a month, during this same period. The single SCAN (Soil Climate Analysis Network) site provides soil temperature, soil moisture, and weather data elements but does not
measure snow due to its location in an agricultural field at a lower elevation where snow is ephemeral.

Precipitation from five low elevation National Weather Service (NWS) cooperative observer sites is also used in water supply forecasts. The five water supply forecast points within the basin are located at long-term stream gauges that provide historic and current streamflow data collected by the BOR, U.S. Geological Survey (USGS) and the Oregon Department of Water Resources.

Water Supply Forecasting

A water supply forecast is the expected volume of water available during a specific period of time at a specific location. Examples include lake inflow, reservoir inflow or flow at stream gauge over a multi-month time step or season. In the western United States, statistical forecasts are also made for annual events such as peak flow and date of the peak and for recession (low flow) dates and stage. Seasonal water supply forecasts are used for water management decision-making such as flood management, irrigation, municipal use, wildlife and fish, hydropower, and recreation. The seasonal volume forecasts are often used as an input for daily water management models.
Water supply forecasting in the Klamath Basin is based on statistical models relying on a linear regression of historic monthly hydroclimatic input variables (SWE, precipitation, streamflow) against historic observed streamflow volume. These regression equations are developed using the principal components statistical method developed by Garen (1992). The principal components method was developed to account for the intercorrelation among predictor variables (which especially affects precipitation and snow observations for a given time period among stations).

Once an initial set of candidate stations and climate elements has been selected, screening is done both manually and with the help of an automated search routine. A final set of predictor variables is selected balancing statistical optimality (i.e., minimizing the standard error) with the selection of hydrologically meaningful variables. Consistency in the variable usage from month to month during the forecast season is important to minimize forecast fluctuations and to ensure physical interpretability of the forecasts. As a robust measure of model accuracy, a jackknife test is performed. The test is an iterative procedure of removing each year’s observations one at a time, recomputing the model’s regression coefficients, predicting the removed year, then returning that year’s observation and removing the next one. This is repeated until a series of predictions is obtained, each of which is from a model that did not include the respective year in the calibration. This test is used to evaluate each candidate model, and the standard error calculated from the jackknife predictions is used to develop confidence bounds around forecasts. The statistical models are normally developed with 20 to 40 years of data to ensure the robustness and physical representativeness of the statistical relationships. Each monthly forecast model is developed independently. Thus, a given month’s forecast is not dependent on the previous month’s forecast, although consistency is maintained by using similar data stations from month to month.

Artificial Neural Network Model

As one experiment to improve water supply forecast accuracy, the USGS tested the Artificial Neural Network (ANN) model (Figure 2). This statistical method is a flexible mathematical structure capable of describing complex nonlinear relationships between input and output data sets that are typically found in natural systems (Risley, et al., 2005). The USGS also tested the autoregressive artificial neural network using past streamflow to predict future streamflow volumes for 1979 through 2003 in a weekly time step (Risley, et al., 2005). In both of these techniques, forecasts were developed for the five forecast points in the Klamath Basin for the months of January through June and were compared to the principal component method. In the comparison, the principal components model performed better at all forecast points in April, though there were mixed results in other months, suggesting there would be little to gain if the ANN method were adopted.

New Variables for Statistical Models

Several new variables were evaluated for their potential in improving water supply forecast accuracy with principal components regression models. These variables include those representing groundwater conditions (wells and springs), the average monthly temperature during the spring season to assist in describing snowpack melt conditions, a new climate
teleconnection index (Trans-Niño Index) to indicate climate conditions for the upcoming winter, and the basin mean areal precipitation. These variables were analyzed in conjunction with the current variables used in the forecast equation (SWE, precipitation, streamflow).

![Neural Network Diagram](image)

**Figure 2.** An example of a neural network model architecture with three input layers, five hidden later nodes, and a single output. (Risely, et al., 2006).

**Wells and Springs**

From other studies in the Klamath Basin, it is known that groundwater flow and storage are significant components of the basin hydrology due to its volcanic nature. Data from wells and springs in the basin were reviewed, and it was determined that one Oregon Department of Water Resources observation well had a long-term dataset that could be edited and used, and one Oregon Department of Water Resources streamflow gauge that measures a large spring shortly after it begins to flow had a data set that was robust and quality controlled. Both of these data sets provide good correlation to the spring and summer streamflow in the Klamath basin. The single correlation between the spring streamflow at Fall River to the Williamson River streamflow ranged from 0.28 to 0.59. The correlation was better in the forecasts for later season summer flows, which is logical in that the springs would be best correlated with summer baseflow. The well level correlation to the Williamson streamflow was also good at -0.45 to -0.52, as the depth to groundwater is another good indication of baseflow conditions.
Spring Season Temperature

While spring temperature is a critical element in physically based models, it has rarely been used in statistical models. It was surmised that the temperature during the months of March, April, and May would be of help in forecasting streamflow by indexing snowpack ripeness, melt rates, and evapotranspiration losses. Obviously, this is a negative relationship, where warmer temperatures are associated with lower streamflow. The only station with a sufficiently long temperature record was Crater Lake National Park Headquarters, located at the northwestern edge of the basin. It was found that the correlation coefficients between average temperature during March, April, and May and the subsequent seasonal streamflow volume were in the range -0.26 to -0.53. Of the three months, March provided the best correlation to subsequent streamflow. These variables, then, are useful for improving the accuracy of forecasts issued in the months of April through June.

Climate Indices

There are several standard climate indices that are used in water supply forecasting in the western United States and elsewhere. The Southern Oscillation Index (SOI) is used in some parts of the Pacific Northwest, the northern Rocky Mountains, and the Southwestern states of Arizona and New Mexico. There is a region between these two areas that does not have a strong correlation with the SOI, and the Klamath Basin falls on the edge of this area. The Pacific Decadal Oscillation (PDO) is also not well correlated, but it is useful in identifying decadal-scale climate regimes. A new index, the Trans-Niño Index (TNI), was the focus of our work. The TNI, first published by Trenberth and Stepaniak (2001), is the standardized equatorial sea surface temperature (SST) gradient between the Niño 1+2 and Niño 4 regions (Figure 3). The evaluation was limited to 1980-2004 to align with the current climate regime as defined by the PDO. The TNI during the fall and early winter provides a good correlation (r of approximately 0.7) to streamflow in this current warm PDO phase. Recent work has shown that there is a broad regional pattern of TNI correlation to streamflow (Kennedy et al., 2005).
Mean Areal Precipitation

Mean areal precipitation was calculated as spatial averages derived from monthly time series grids estimated with the Parameter-Regression on Independent Slopes Model (PRISM) (Daly et al., 1994; http://www.ocs.orst.edu/prism).

The monthly mean areal precipitation data series derived from PRISM grids were compared to the individual station data series. The correlations of each month’s data to the subsequent April-September streamflow for the Williamson and Sprague sub-basins are shown in Figures 4 and 5. These figures indicate that the mean areal precipitation derived from the PRISM grids have better correlations with streamflow overall than any individual station. Individual stations may have a better correlation for one or more months, but for the season, the more robust and consistent correlation of the areal precipitation is preferred.
Figure 4. The correlation of the monthly mean areal precipitation and individual stations with April through September streamflow volume in the Williamson subbasin.

Figure 5. The correlation of monthly mean areal precipitation and individual stations with April through September streamflow volume in the Sprague subbasin. (Kennedy, et al., 2005).
Conclusion

Forecasting future water supplies continues to be the primary planning tool for water resource management in the western United States and especially in the Klamath Basin. There will continue to be emphasis on improving the forecast accuracy for better decision making for the multiple and often conflicting water resource needs. This is complicated by unique basin characteristics, extreme weather events, and changing climate conditions.

Snowpack, precipitation, and streamflow have been long standing good predictors of future streamflow. They will continue to be the mainstay of statistical forecasting in the western United States. This study examined several new variables that improve forecast accuracy, and have potential for use in statistical streamflow forecasting models beyond the basin under study. These variables include groundwater data (wells and springs), spring season temperature, climate teleconnection indices (especially the Trans-Niño Index), and mean areal precipitation derived from spatial grids. The groundwater variables provide long-term, multi-seasonal conditions of the basin hydrology and the baseflow characteristics. The temperature and mean areal precipitation variables are related to the current weather, and they improve our knowledge of the status of the snowpack and resulting streamflow in the basin. The Trans-Niño Index provides a much needed early prediction of the future weather expected in the basin. Early season forecasts allow additional time for the implementation of conservation and mitigation measures to offset any water shortages or surplus. All of these variables have a good correlation to the streamflow period of interest and together provide an increase in forecast accuracy. The forecast techniques and variables used here may also have applicability in other basins where hydrometeorological and climate variables contain sufficient information to make useful streamflow forecasts.

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Operational Hydrologic Simulation Modeling at the Natural Resources Conservation Service’s National Water and Climate Center

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Abstract

This paper describes the current status and anticipated near-term future directions of the U.S. Department of Agriculture’s Natural Resources Conservation Service’s (NRCS) National Water and Climate Center with respect to the use of hydrologic simulation models. It begins with a description of the water supply forecasting operations, and continues with a review of past attempts to adopt operational hydrologic simulation models. Next, the modeling environment is described, with emphasis on one model, the Precipitation Runoff Modeling System (PRMS) and its environment, the Modular Modeling System (MMS). Case studies of two basins are provided. For the sake of brevity, many of the NRCS’s other simulation modeling activities are not included. Nonetheless, in the final sections, general aspects of simulation modeling in an operational environment are discussed, ranging from model calibration to the role of multiple models. The final section is relevant to any operational modeling enterprise, regardless of the specific model or methodology chosen.

History

For close to 70 years, NRCS has provided seasonal water supply outlooks for use by western U.S. water managers. These outlooks are a critical component in effective water management and are utilized by a broad spectrum of users for a variety of purposes, ranging from irrigated agriculture, flood control, municipal water supply, endangered species protection, power generation, and recreation.

The Water and Climate Services division of the NRCS National Water and Climate Center produces seasonal water supply outlooks monthly, January through June, in partnership with the National Weather Service (NWS) and local cooperating agencies, such as the Salt River Project in central Arizona. During the 2004 forecast season, four NRCS hydrologists issued over 10,000 seasonal water supply outlooks for over 630 locations. Near the start of the month, each forecaster typically has less than 3 working days to create, analyze, adjust, coordinate, and issue forecasts for over 160 points simultaneously. The geographic and climatic scope of the forecasts range from minor creeks of the semi-arid southwestern United States to glaciated basins of the Arctic Circle. Any new forecasting techniques would need to address many of the unique demands of this time-critical, yet human and computer-resource limited operational environment.

Improving these forecasts is one method of improving the sustainability of water supplies in the western United States. Increasing competition over limited resources also demands more
informative forecast guidance, directly related to the user’s situation. For example, while it may help a user to have an estimate of the anticipated April-July runoff volume at a specific location, his or her legal water right may be tied to the date that flow falls below 225 cubic feet per second. Such user interests are so varied and specific that it is not possible for a forecaster to maintain an armada of statistical regression equations to address (and anticipate) every user need. Instead, the forecaster could present an ensemble of plausible hydrographs from which a specific forecast would be derived by the user. A hydrologic simulation model can provide such a forecast if properly calibrated and provided with the appropriate data.

Also, a simulation model, with its representation of basin physics, can explicitly capture basin behavior during extreme years, e.g., unprecedented snowpack, and multi-year soil moisture deficits. In contrast, the current statistical forecast methodology is relatively limited and does not quantify the effects of highly unusual or even unprecedented conditions.

This paper describes the current status and anticipated near-term future directions of the NRCS National Water and Climate Center (NWCC) with respect to the use of hydrologic simulation models. The emphasis is on one model, the Precipitation Runoff Modeling System (PRMS) and its environment, the Modular Modeling System (MMS). Then general aspects of simulation modeling in an operational environment are discussed, ranging from model calibration to the role of multiple models, which are relevant to any operational modeling enterprise.

**NRCS Monitoring History**

Along with producing water supply forecasts, the NRCS is also responsible for operating a high-elevation hydroclimatic monitoring network. Until the early 1980s, these measurements were manually collected by snow surveyors traveling to a site on a monthly basis to use a federal snow sampler (a specially calibrated hollow aluminum tube) to measure snow water equivalent and snow depth. Increasing demands for more timely and frequent snowpack information resulted in a significant push to automate and telemeter measurements from nearby snow courses using meteor-burst communications. Thus the SNOTEL (SNOw TELemetry) network was funded and deployment began in the middle 1970s. Some of the original justification for the SNOTEL network was a demand for daily real-time measurements for use in hydrologic simulation models. Therefore the NRCS has long had an interest in adopting a simulation model for operational forecasting, and this interest has been intricately tied to the data monitoring network. Leavely and Saindon (1985) and Marron (1986) investigated the use of PRMS in an NRCS operational setting, primarily focusing on basins in Nevada. These authors also tried to constrain model parameters so the model simulated snowpack during calibration-matched SNOTEL snow-water equivalent measurements.

Several NRCS hydrologists (Jones 1986 and Perkins 1988) operated the U.S. Army Corps of Engineers Streamflow Synthesis and Reservoir Regulation (SSARR) model on the Yellowstone and Upper Rio Grande, following the NWS’s SSARR-based simulation of the Clearwater River in Idaho (Kuehl, 1979). Perkins was a former Army Corps employee and helped write part of the original SSARR computer code. These authors, likewise, compared simulated snowpack to SNOTEL measurements. Cooley (1986) of the USDA-Agricultural Research Service tested the NWS River Forecast System (NWSRFS) model on Lower Willow Creek in Montana, in
cooperation with NRCS personnel. Shafer, et al., (1981) also forced the Snowmelt Runoff Model (SRM) with satellite data to produce forecasts, which was followed by more involvement in the satellite version of SRM around 1987.

All these activities built up to an internal NRCS document in 1992 comparing the results of different models and outlining a strategy for moving from forecasting prototypes to an operational system. This document identified the SSARR model as the most attractive option and committed to calibrating 200 basins in 5 years with 3 staff hydrologists. Running on a Unix 33-Mhz 386 mainframe with DOS 286 workstations, the entire enterprise was expected to cost $1.217 million. Soon after this document was released, the NRCS suffered an unexpected and significant realignment of resources; parts of the agency were reorganized, and the simulation modeling enterprise lost much of its momentum. A position at the NWCC was moved out of water supply forecasting and was devoted to simulation modeling after the 1992 report; recognizing that the agency would not have the resources to attempt operational simulation modeling after the agency reorganization, efforts of this hydrologist were turned towards more research-oriented spatially distributed snow simulation models (e.g., Garen and Marks, 1996, 2001). These snow models would eventually be a component in a next-generation spatial hydrology model likewise being developed by the research community.

A program-wide meeting of the snow survey and water supply forecasting organization was convened in 2002 in Las Vegas. At this meeting, a committee was formed to investigate the feasibility of running hydrologic simulation models in the current operational environment. With relatively fewer budget constraints, and with improved automation and data availability, the window of opportunity appeared open to at least explore the available possibilities. In addition, with the unprecedented sequence of wet and dry years at the end of the 20th century, the call arose from users asking NRCS to provide more and better information about extreme events and forecasts of within-season hydrograph behavior. Our committee formulated a plan to investigate the use of a modified version of the SRM model, as well as PRMS, the University of Washington Variable Infiltration Capacity (VIC, Wood, et al., 2001), and NWSRFS models. The implications of maintaining the status quo and/or serving as a conduit for another agency’s forecasts were also identified.

Model Selection

A simulation model is a mathematical representation of processes that influence primarily the energy and water balances of a watershed. These models have a broad range of relevant scales, from continent to catchment, and have varying complexity, from highly lumped generalized conceptualizations to models with explicit representations of basin physics. No model is adequate for all circumstances; and the selection of a model (or models) involves balancing accuracy, practicality, data demands, and the ability to calibrate the model to the specific watershed.

As described by Leavesley, et al., (1983), PRMS is a modular-design, deterministic, distributed-parameter modeling system developed to evaluate the impacts of various combinations of precipitation, climate, and land use on streamflow, sediment yields, and general basin hydrology. Basin response to normal and extreme rainfall and snowmelt can be simulated to evaluate
changes in water-balance relationships, flow regimes, flood peaks and volumes, soil-water relationships, sediment yields, and ground-water recharge. Parameter-optimization and sensitivity analysis capabilities are provided to fit selected model parameters and evaluate their individual and joint effects on model output. The modular design provides a flexible framework for continued model-system enhancement and hydrologic-modeling research and development.

PRMS resides within the larger MMS framework which allows the user to construct a model from individual modules, such that a model could be designed to match the situation at hand. For example, if basin hydrograph behavior is heavily influenced by groundwater, the standard PRMS subsurface water module could be replaced by a module with a more appropriate level of detail. The MMS infrastructure allows the design of individual models but it also facilitates the use of many different models on an individual basin because the input and output data formats are universal.

Data Collection and Quality Control

Accurate and representative meteorological data are key to the successful operation of hydrologic simulation models. This data plays a role during model calibration as well as real-time operations. The data demands of a forecasting agency are somewhat different than those of a group setting up a model for research purposes. Forecast models must be able to run on demand, capturing recent events less than hours after they occur. Likewise, real-time data are often of the most dubious quality, especially from automated measurement systems which can randomly produce extreme (but unlikely) values or possess gradual drift. Without automated data acquisition technology and automated, forecaster-aided intelligent data quality control, it’s unlikely that the human resources of the NRCS would be able to satisfy the data demands of a single basin, much less the hundreds of basins planned.

The primary driving variables for most hydrologic simulation models are daily temperatures and precipitation amounts, although some models also ingest or assimilate snow water equivalent, snow covered area, and other variables such as surface radiation. The NRCS SNOTEL sites primarily measure current snow water equivalent, accumulated precipitation, and temperature. Many sites have recently installed soil moisture, soil temperature, and snow depth sensors. A very limited number of sites measure wind speed and direction, solar radiation, relative humidity, and/or fire fuel moisture.

The NWS also maintains a variety of networks consisting of low elevation sites, some with automated measurements others with manual measurements taken by cooperative observers (COOP). Precipitation and temperature are routinely measured although accurate snowfall and snow depth measurements are less common. Daily SNOTEL measurements generally began in the early 1980s although many of the COOP data sites have existed since the early 1900s, with widespread data available since 1948.

A recent significant advance in the availability of real-time and historical climate data is the advent of the Applied Climate Information System (ACIS, Hubbard, et al., 2004). This distributed and synchronized information network is maintained and operated by the Regional Climate Centers and the National Climate Data Center. It serves data from U.S. National
Oceanic and Atmospheric Administration (NOAA) networks including the COOP network, the Hourly Surface Airways Network, and the Historical Climatology Network. ACIS can be accessed through high-level, Web-based interfaces or directly through a Python language-based XML-RPC standard. The Python interface allows, among other things, for the user to submit a list of sites, desired dates, and variables at a command prompt and be returned to a machine readable file containing the data. Through a series of Cygwin (a UNIX emulator for Windows) shell scripts, precipitation and temperature data through yesterday are currently being retrieved from the ACIS system and the NWCC ftp server, and are being combined with streamflow data automatically downloaded from the U.S. Geological Survey (USGS) Web page to create model-ready files for forecast execution.

In addition to the real-time data, it is important to create and maintain an extremely high quality historical dataset, subjected to the most rigorous screening and data quality testing possible. The NRCS focuses most of its resources in maintaining the quality of its snow water equivalent and precipitation data. Temperature data however are largely “raw” (a recent inventory showed between 99.7% and 99.9% of historical SNOTEL temperature measurements were never altered from the original sensor value). The data possesses many outliers that must be removed and replaced with suitable alternative values for any simulation model to have any chance of accurately reproducing basin hydrologic conditions.

As mentioned in Clark and Slater (2006), one of the authors (Martyn Clark) developed a quality control software package drawing on the best aspects of at least four other major quality control approaches including “point-based and spatial checks for a) extreme values; b) internal consistency among variables (e.g., maximum temperature less than minimum temperature); c) constant temperature (e.g., 5 or more days with the same temperature are suspect); d) excessive diurnal temperature range; e) invalid relations between precipitation, snowfall, and snow depth; and f) unusual step changes or spikes in temperature time series.” This procedure was used to identify suspicious values throughout the historical period of record of the SNOTEL and ACIS datasets and replace them with suitable alternatives where appropriate. This software has been transferred to the NRCS for the package to be used to screen real-time data. The NRCS is also investigating the use of the PRISM screening technology (Daly, et al., 2004).

Model Calibration

Hydrologic simulation models contain equations that describe the physical interaction of different components of the water and energy balance. Model parameters relate these abstract physical laws (or scale-dependant approximations of these laws) to the specific basin at hand. Many parameters are observable (e.g., basin area, slope, elevation, vegetation type) although some parameters are unobservable conceptualizations of basin characteristics (e.g., the nonlinearity of hydrologic response to near surface soil moisture saturation). While the ultimate goal of a model based completely on observable parameters may not be realized for several years, another key to simulation modeling success is the accurate calibration of parameters. Of particular concern to NRCS operations is the labor intensiveness of manual calibration (human guided stepwise adjustment of model parameters followed by visual inspection of model hydrograph behavior compared to the observed). Instead, the agency is seeking to measure as
many parameters as possible, use automatic calibration techniques to estimate remaining parameters, and use manual calibration only when necessary as a last resort.

The spatial parameters of the PRMS model are derived using the “GIS Weasel” an ArcInfo based map and user interface driven tool to delineate, characterize, and parameterize the hydrologic response units of the model (Viger, et al., 1998). This program ingests elevation, soils, and vegetation data; and queries the user about his or her assumptions in defining a hydrologically homogeneous unit then automatically processes the spatial data to generate initial parameter estimates. A modified version of the Weasel is being tested, which uses a fixed strategy for sub-basin delineation and involves little to no human interaction with the program. Such easy, automated, and fast batch estimation of model parameters is an attractive option to agencies with limited personnel.

At this stage, many non-spatial parameters remain to be calibrated. Classically, these steps of model calibration would involve the manual adjustment of model parameters to improve the visual correspondence of the model and observed hydrographs. The danger in such calibration, especially by novice modelers, is the problem of equi-finality (the notion that many different parameter combinations would provide an equally acceptable fit to the hydrograph). While model output between two parameter sets during calibration may be nearly identical, the internal simulation of model states (e.g., the amount of snow on a watershed, the depth of water contained in soils) may be radically different. Parameter sets that “got the right answer for the wrong reason” are likely to perform poorly outside of the calibration period. Therefore it is critical to verify the intermediate states of the model during calibration.

Hay, et al., (2006) have developed an iterative multi-step automatic calibration scheme which was used to derive several initial parameter sets for operations during 2005. This procedure identifies specific parameters that influence the simulation of model states; exogenous datasets are then used to constrain model internal behavior. For example, model parameters related to solar radiation are identified in advance using sensitivity analysis. All other parameters are held constant and the UA-Shuffled Complex Evolution algorithm (Duan, et al., 1994) is used to identify the parameter combinations that give the best fit between the model’s simulated solar radiation monthly climatology and observed solar radiation climatology. When an optimal parameter combination is found, the next step of the calibration related to potential evapotranspiration begins, relating the model monthly climatology to the observed. The 3rd and 4th rounds of calibration involve the verification of the annual water balance and the partial duration time series of peak flows above a specified threshold of low flows. The final parameter set is then returned to the first step and the calibration of solar radiation parameters is repeated. In all, the program cycles through all 4 steps 6-8 times until the program converges on an optimal parameter set that satisfies all objectives. This process remains under development and the addition of other exogenous datasets (e.g., snow covered area, snow water equivalent) is being investigated.
Model Operation

In the summer of 2004, 13 basins were identified as suitable initial candidates for an attempt to calibrate, run, and analyze PRMS models (Table 1). After exceptional fall rainfall, and record breaking streamflows following several years of extreme drought, personnel recognized a unique climatological opportunity to test the models and added 3 basins in southern and northern Utah. In the first season, 16 basins were calibrated with multiple parameter sets – the first set used all available input data, and a second used only a subset of those meteorological sites whose data are available in real-time (e.g., some NWS cooperative observers report a month’s worth of data only once a month, an unacceptable timeline for real-time operations). The first dataset is likely to give the best calibration results, but may perform poorly during forecasting if many sites are missing data. The second calibration set should provide a more robust estimate of real-time performance even if the calibration is less than optimal. Third and fourth possible parameter sets are anticipated using a historical dataset with serially complete backfilled meteorological data values.

Table 1. Forecast basins and their characteristics. Latitude and longitude are the location of the streamgage. Natural Resources Conservation Service, National Water and Climate Center.

<table>
<thead>
<tr>
<th>Station ID</th>
<th>Site Name</th>
<th>Latitude (North)</th>
<th>Longitude (West)</th>
<th>Drainage (Miles²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>06024450</td>
<td>Big Hole River Bl Big Lake Cr at Wisdom, Montana</td>
<td>45.62</td>
<td>113.46</td>
<td>575</td>
</tr>
<tr>
<td>06191500</td>
<td>Yellowstone River at Corwin Springs, Montana</td>
<td>45.11</td>
<td>110.79</td>
<td>2,619</td>
</tr>
<tr>
<td>06694650</td>
<td>Antero Reservoir Inflow, Colorado</td>
<td>38.98</td>
<td>105.90</td>
<td>189</td>
</tr>
<tr>
<td>08378500</td>
<td>Pecos River near Pecos, New Mexico</td>
<td>35.71</td>
<td>105.68</td>
<td>189</td>
</tr>
<tr>
<td>08379500</td>
<td>Pecos River near Anton Chico, New Mexico</td>
<td>35.18</td>
<td>105.11</td>
<td>1,050</td>
</tr>
<tr>
<td>09112500</td>
<td>East River at Almont, Colorado</td>
<td>38.66</td>
<td>106.85</td>
<td>289</td>
</tr>
<tr>
<td>09239500</td>
<td>Yampa River at Steamboat Springs, Colorado</td>
<td>40.48</td>
<td>106.83</td>
<td>568</td>
</tr>
<tr>
<td>09251000</td>
<td>Yampa River near Maybell, Colorado</td>
<td>40.50</td>
<td>108.03</td>
<td>3,410</td>
</tr>
<tr>
<td>09299500</td>
<td>Whiterocks River near Whiterocks, Utah</td>
<td>40.59</td>
<td>109.93</td>
<td>109</td>
</tr>
<tr>
<td>09361500</td>
<td>Animas River at Durango, Colorado</td>
<td>37.28</td>
<td>107.88</td>
<td>692</td>
</tr>
<tr>
<td>09406000</td>
<td>Virgin River at Virgin, Utah</td>
<td>37.20</td>
<td>113.18</td>
<td>956</td>
</tr>
<tr>
<td>09408400</td>
<td>Santa Clara River near Pine Valley, Utah</td>
<td>37.38</td>
<td>113.48</td>
<td>18.7</td>
</tr>
<tr>
<td>12358500</td>
<td>Middle Fork Flathead River near West Glacier, Mont.</td>
<td>48.50</td>
<td>114.01</td>
<td>1,128</td>
</tr>
<tr>
<td>13010065</td>
<td>Snake River Ab Jackson Lake at Flagg Ranch, Wyo.</td>
<td>44.10</td>
<td>110.67</td>
<td>486</td>
</tr>
<tr>
<td>13105000</td>
<td>Salmon Falls Creek near San Jacinto, Nevada</td>
<td>41.94</td>
<td>114.69</td>
<td>1,450</td>
</tr>
<tr>
<td>13147900</td>
<td>Little Wood River Ab High Five Creek near Carey, ID</td>
<td>43.49</td>
<td>114.06</td>
<td>248</td>
</tr>
</tbody>
</table>

The spatial model calibration was completed by NWCC personnel on regular desktop computers described below. From downloading elevation data to finishing spatial calibration takes approximately 30-45 minutes per site, depending on the size and complexity of the basin. The automatic multi-objective calibration was done using the USGS Denver office’s Beowulf computer cluster, taking approximately one day of computing time per basin. By October 2005, a java-based visual user interface to the internal-state calibration software was ready for testing on computers in the NWCC office.

In real-time forecast operations, models are initialized by running the model over the period of record of the input dataset (1948-2005) and saving the model states (e.g., snow covered area, snow water equivalent, and soil moisture) on the last day of the run. Forecasts are then created
by forcing the model with the meteorological sequence of each historical year in turn, given the same initial model state. The result is an ensemble of equally likely possible futures, given current basin conditions. This ensemble streamflow prediction (ESP, Day 1985) technique has become a standard practice among most operational hydrologic forecast agencies. Although all historical years are run, a subjective visual analysis of input and output calibration time series was done in advance to specify a start year for acceptable traces; in many basins, the change in calibration performance was obvious when the mix of available stations changed. At the most extreme, some basins have no input data early in the period of record before any COOP or SNOTEL sites existed in the region. Inclusion of these sequences in the analysis would be clearly inappropriate.

As of May 2005, identical data collection and modeling systems were operating successfully on several computers at the NWCC as well as on a computer at the Utah NRCS snow survey data collection office and a personal home computer outside the NRCS network. All 16 basins can be run on demand for multiple parameter sets. On a standard 2.8 GHz desktop computer with 1GB of memory with a transfer rate of 1 Mbps, the data requirements for 16 basins across the western United States can be satisfied in less than 8 minutes. Improvements in database technology are likely to reduce this time, as will be necessary when more basins are adopted. Model initialization and ESP simulations for all basins, with two parameter sets per basin, are completed in 8 minutes. Currently the data collection and model operation routines are running on a scheduler four times a day (to collect late-reporting sites).

An Excel spreadsheet has been temporarily designed to ingest model output files, link to real-time streamflow data, visualize hydrograph behavior and calculate summary statistics. The user can visualize one of 18 model states (e.g., streamflow, snow covered area, temperature, and soil moisture) overlaying the real-time forecast distribution (or a subset of individual years) on top of the model simulated history and/or the observed data where available. The user can also calculate the historical and forecast peak amount, peak date, first date of crossing below or above a relative or absolute threshold, the volume above a threshold, and so on for any of the model states. Additional advanced Java-based spatio-temporal visualization tools were available by September 2005 with the transfer to the Object Modeling System (OMS), the next incarnation of MMS.

Case Study 1: Santa Clara Near Pine Valley, Utah

The streamgage on the Santa Clara River near Pine Valley drains a small, relatively high elevation unregulated watershed dominated by snowmelt. The region recently experienced an unprecedented exceptional drought. In February 2004, the basin was designated as D4, the most extreme drought classification available on the U.S. Drought Monitor (http://www.drought.unl.edu/dm/monitor.html), reserved only for events with return intervals more than 50 years. In 2002 the lowest streamflows on record were recorded; and flow from 1999-2004 was 47 percent of the long-term 1971-2000 normal rate.
Beginning on October 17, 2004, however, Utah was struck with a slow moving high-intensity storm (Bardsley and Julander, 2005). The Virgin and Santa Clara river basins experienced between 4.7 and 10.9 inches (11.938 cm. and 27.686 cm) of precipitation during October 17-23. It is estimated that one station (Gutz Peak) experienced a 24-hour precipitation amount in excess of the 1,000-year return interval. On October 21, SNOTEL soil moisture sensors rose to levels usually only reserved for full snowmelt season and persisted there for the next several months. The PRMS model soil moisture states reflected that the current year had gone well outside the range of historical variability (Figure 1). The complexity of the situation increased when in early January unprecedented snowfalls hit the region. During December 28 to January 13, 2005, sites received as much as 20 inches (50.8 cm) of new snow water equivalent on top of already record high snowpack. The snowpack was so extreme that nearby Midway Valley (NRCS Station ID: 12m23s) broke the all-year, all-time snowpack records by mid February, 2 and ½ months earlier than the previous record set in 1983; and eventually peaked out in mid April at 140 percent of the previous record, which was close to 270 percent of average. PRMS did a fair simulation of the timing and character of streamflows (Figure 2).

Figure 1. PRMS soil moisture simulation, Santa Clara River. Gray background indicates the model simulated climatology from 1984-2003, including the historical minimum, maximum, median and 10 and 90 percent exceedence probabilities. Heavy black dotted line shows simulated 2005 values and solid and dashed lines are the forecast 10, 50, and 90 percent exceedence probabilities issued June 29, 2005.
Figure 2. PRMS streamflow simulation, Santa Clara River. Gray background indicates the observed climatology from 1984-2003, including the historical minimum, maximum, median and 10 and 90 percent exceedence probabilities. Solid black line shows simulated 2005 values and the dashed line with triangles represents the observed. Data after June 29 represents the streamflow forecast exceedence levels, as Figure 1; note underdispersion of forecast ensemble spread (i.e. the forecast 10, 50 and 90 percent exceedence probabilities are overlapping).

The model captured the unprecedented winter baseflow conditions and reproduced the overall shape of the hydrograph rise in May and June. It is difficult to know the accuracy of the real-time streamflow data during very high flows although it does seem like the model had a tendency to undersimulate flows, both during the October event and during May-June. Near May 1, the model predicted a 50 percent chance of having a seasonal peak greater than 125 cubic feet per second (cfs) (3.54 cubic meters per second [cms]), whereas the NWS official forecast indicated a 50 percent chance of more than 450 cfs (12.7 cms). The spring precipitation sequence was not unusual, and the eventual peak for the season was 184 cfs (5.21 cms) observed on May 24. The NRCS has no interest in or authority to issue statements related to flooding, and at this time there is no information about whether a slight under forecast would have had a more damaging effect to the user than a larger over forecast.

Case Study 2: Little Wood River Near Caret, Idaho

The stream gage on the Little Wood River above High Five Creek near Carey, Idaho, is at an elevation of 5,320 feet (msl) (1,620 meters) and drains an area of 248 square miles (642 square kilometers). The mean elevation of the basin is 7,220 feet (2200 m). Diversions above the gage are used to irrigate 1,300 acres (526 hectares), which is less than one percent of the basin. The
forecast for this location is used to manage the Little Wood Reservoir, which serves downstream irrigators, but is also important for recreation, fish and wildlife, and a small amount of hydroelectric power generation.

Prior to the 2005 water year, the Little Wood watershed was in the midst of a multi-year dry period that started in 2000. Despite a wet summer and fall, the streamflows at the High Five gage were flowing below normal. A series of nine small storms starting on March 19th and ending on May 9th, served to build upon a meager snow pack and to increase the water content of the soil profile (enhancing the expected runoff efficiency). Each of these storm events produced a half inch or less of precipitation. The period of May 15th through May 19th experienced copious amounts of precipitation over southern Idaho generally, and over the Little Wood basin specifically (>4” (10.2 cm) of precipitation). Streamflows in southern Idaho streams and rivers rose dramatically in response to these heavy precipitation events.

The PRMS model simulation matched the timing and magnitude of streamflows (Figure 3). The model tracked the two rapid rises that occurred on May 17th and May 19th, the days of heaviest precipitation. The model produced daily average flows of 1,590 cfs (45 cms) on May 17th and 1,970 cfs (55.8 cms) on May 19th, versus observed values of 1,593 cfs (45.1 cms) and 1,972 cfs (55.8 cms), respectively. It should be pointed out that the model is calibrated on daily average flows. The recorded instantaneous flows were 2,130 cfs (60.3 cms) on May 17th and 2,220 cfs (2220 cms) on May 19th, highlighting how a daily model would clearly not be sufficient if one were attempting to, for example, protect against flood damage.

![Figure 3. PRMS streamflow simulation, Little Wood River. See figure 2 for symbology. Historical and conditional years include 1987-2003. Similarly note underdispersion of forecast future flows.](image-url)
While the simulation of this event was excellent, the spring precipitation event was of an extremely large magnitude and was unanticipated. It is likely that the observed streamflow would have been the edges of the conditional distribution of a forecast issued in February or March. Seasonal- and medium-range precipitation and temperature forecasts might have improved the accuracy of the streamflow forecast, but this situation is a clear example of the need to communicate the uncertainty and range of possibilities of outcomes, and to avoid reducing the forecast to “one number” or a single hydrograph trace.

Operational Concerns and Strategies

While the universe of products available from hydrologic simulation models is much more inclusive than statistical-based forecasts, simulation models are much more complex and involve setting up and maintaining. There are many opportunities for errors. Some errors are practically unavoidable, such as those due to extreme precipitation events after the forecast issue date. However, hydrologists should also try to minimize the effects of limitations in model structure, poor model calibration, and errors in input forcings. Additional opportunities exist in the post processing of forecasts and real-time adjustment of model states.

Models

It is essential to have a model or models that are complex enough to describe the hydrology of western U.S. river basins. This includes the accurate simulation of snowpack as well as soil moisture, and the spatial interpolation of forcing variables (e.g., temperature and precipitation) over complex terrain. MMS allows the ability to tailor the model structure to fit the situation at hand. In particular, it is critical for the agency to retain flexibility to adjust to evolving forecast needs and not be fixed into “one model.” For example, the NRCS envisions playing a larger role in simulation modeling of water quality for agricultural processes. The MMS infrastructure makes such growth possible while maintaining the same overall architecture of data handling. If the model does not have the correct structure for the basin hydrology, the forecaster will have to hope, at best, that time-consuming subjective real-time adjustment to model states and parameters can compensate for these limitations.

Inevitably, all models are imperfect representations of reality, and each is a different perspective on a system. Operational hydrology often focuses on the use of a single tool or a single model in developing forecast guidance. In many natural science and economic settings, research consistently reveals that a consensus forecast based on the output of many tools almost always outperforms the best individual tool within the ensemble (Armstrong, 2001). The approach of creating forecasts based on an ensemble of tools (e.g., “Super-ensembles”) has gained acceptance in the operational meteorological and climatological communities, and the evolution of hydrologic practice along these lines would be logical and would benefit users. Previously, the resources required to maintain many different modeling systems made such an enterprise prohibitively expensive, especially if the incremental improvement in the forecasts was small compared to the cost of maintaining many different systems. Operational meteorologists and climatologists rely heavily on automation and leverage partnerships with outside research groups (e.g., universities) running their own models; there is no reason the same approach could not be used by hydrologists.
Parameters

In relating a generalized model to a specific basin, it is necessary to estimate model parameters. As mentioned earlier, so-called “observable” parameters are preferred to non-observable parameters because human expertise is often required to subjectively estimate the non-observable ones. Much research has been done in objective automatic calibration of hydrologic models although this practice has not received widespread operational acceptance. A concern is that automatic calibration procedures “possess logic” but “lack sense,” in that they can adjust parameter values to the extremes, in order to achieve the last bit of improvement in the calibration objective function. In comparison, the human forecaster can use subjective knowledge and experience to constrain certain parameter values while preventing over-fitting.

In one sense, the optimal strategy for a resource-limited agency like the NRCS would involve a hybrid of automatic and manual calibration techniques. The hydrologist would have to articulate multiple objectives that he or she would like to satisfy in terms of hydrograph behavior. Next, an objective procedure mimicking manual calibration (e.g., Hogue, et al., 2000) would return to the hydrologist a series of plausible parameter sets. The expertise of the human would then be used to narrow the range of parameter sets and/or make minor adjustments to parameter values. Of course nothing prevents the hydrologist from retaining all plausible parameter sets. The standard ESP procedure accounts for forecast uncertainty due to future climate variability but ignores uncertainty due to parameter estimation, model limitations, and data uncertainty. Running many parameter sets and aggregating the results into a “super-ensemble” would be one way of accounting for parameter uncertainty, provided that one can ensure that the parameter sets are independent samples.

Although it may be beyond the computational resources of the agency at the moment, some researchers have gone as far as suggesting that the model should be recalibrated any time a specific forecast is desired (Moore and Doherty, 2005). Rather than retaining a single “calibrated model” for all situations (e.g., peak flows, low flows, seasonal volumes), the model is recalibrated on demand to fit the exact forecast situation (e.g., the first date after the peak that flow drops below 325 cfs [9.2 cms]). This philosophy borders on treating the model like a complicated non-linear statistical tool. This approach does not satisfy the expectation that the agency should be able to provide a suite of hydrograph traces that give an equally accurate forecast, no matter what aspect of the hydrograph is being analyzed. The agency may have to decide on the most important objective, either a hydrograph based forecast of plausible daily time series, or a tool that gives the most accurate and well-calibrated probabilistic answer to the specific question being asked. Ultimately, resources may be the limiting factor in determining the calibration strategy, both in the sense that the human resources are not available to do manual calibration and computer resources are not available to do the most sophisticated forms of automatic calibration. In addition, it is not enough for a calibration approach to “have the science right.” If it is not easy to install or operate, does not have an adequate user interface, or is not fully credible to the hydrologist, the likelihood of operational adoption is low.
Data

Without real-time access to high quality data, no forecast model can operate successfully. An ideal forecast system would also include a graphical interface to the data, backed by a powerful set of automated quality control routines. A forecaster’s energy should be spent inspecting extreme values and “locking in” the values if they are true. This includes routines that investigate the spatial-temporal consistency and plausibility of the values, identifies the probability that the value is an outlier, and suggests replacement values. Of particular concern is the mistaken rejection of a real extreme value. The forecaster must also be able to retain control over the past data in that if a forecaster changes a value, the original value does not overwrite the forecaster edit when refreshing data, unless the data value changes at the source; in which case the forecaster should be presented with a choice to accept or reject the new value. The forecaster should also have the flexibility to decide to use all raw data, all estimated data, or some mix of original and edited values.

This, of course, assumes that the “true” data value is knowable by the forecaster. Data quality control involves the estimation of uncertain information by looking at the internal consistency of the data and the historical relationships between variables or across sites. Even a manual “ground truthing” of an automated measurement has some instrumental and representativeness errors associated with it. In this sense, the parallels between forecasting the true state of anticipated streamflow and estimating the true value of the forcing inputs (e.g., snowpack, precipitation, and temperature) are uncanny.

From the turn of the century until the 1980s, water supply forecasts were almost exclusively deterministic in that the forecast was for a specific volume at a given location and time period (e.g., “500 thousand acre-feet [617,000,000 cubic meters] for April-July on the Animas River at Durango”). In time, the need to provide users with a probabilistic forecast was recognized, so that the users could determine their respective level of risk and determine the “one number” that is most relevant to their specific operations. Although the focus of forecasters and presentation of the water supply forecast information to users still remains primarily deterministic, there is virtually no operational discussion of data values as probabilistic entities. Such a change philosophy would require a wholesale paradigm shift that is unlikely to occur in the near future. Nonetheless, it is still the responsibility of operational agencies, within the limits of their resources, to adequately and accurately represent forecast uncertainty, including data uncertainty.

Techniques exist to convert deterministic point data values into probabilistic data distributions, such as PRISM (Daly, et al., 2004). Clark and Slater (2006) also describe such a conversion and the linking of gridded precipitation conditional distribution functions with random number generators to create ensembles of adequately spatially correlated precipitation fields. These ensembles can then be used to force the hydrologic model(s) to derive an ensemble of possible model initial states (e.g., snowpack). This will create additional dispersion in the ensemble-of-ensembles forecast, accounting for the data uncertainty. As before, the success of the NRCS in accounting for these factors relies on how well the above concepts can be articulated in a user-friendly software package that does not exhaust available human and computational resources.
Assimilation and Post-Processing

The NRCS data collection and quality control effort is primarily focused on the accurate estimation of snow water equivalent data. Many models ingest precipitation and temperature data to simulate snowpack. The agency should take advantage of the information contained in the snowpack measurements to keep model states on track.

The NWS has for many years assimilated snow data, beginning with the Snow Estimation and Updating System (SEUS, McManamon, et al., 1995), continuing on with variants and modifications to the original design. The University of Washington forecast system projects the current observed snow data into a historical observed percentile which is then projected into a percentile of the model climatology (Wood, et al., 2001). Bales, et al., (2006) recently assimilated satellite snow image data into the PRMS model with limited success. Objective data assimilation is routine and widespread in meteorology, and there is also a long history of subjective modifications to hydrologic model states by the NWS (in order to match real-time simulated flows with observed flows – a significant difference in these two diminishes the credibility of a short-term forecast).

Before assimilation, the hydrologist should be inclined to ask two questions – why is the model simulation not tracking the observed and what are the ramifications of changing a model state? If the model’s simulations are poor due to poor model structure or poor calibration, the forecast issue date is not the time to be adjusting model states, as the credibility of the result is already beyond repair. In an ideal situation, data assimilation should rarely produce large adjustments (e.g., when a small scale major precipitation event occurs between measurement sites). Frequent large adjustments are an indicator that the modeling system itself is fundamentally flawed and should be redeveloped.

Likewise, when a model state is changed (e.g., snowpack is “removed” from the model), what happens to the rest of the model? Did the snow never fall in the first place (in which case it should be “evaporated”)? Did the snow fall and melt unexpectedly (in which case it should go into the soils or have appeared as streamflow)? The implications for the forecast are not trivial; the priming of the soils in the second example is likely to produce a wetter forecast than the first example. Changes in a model state should cascade into other model states. In an obvious example, if a zero snow water equivalent value is assimilated, the snow covered area, also, should be adjusted to zero. Slater and Clark (2006) have tested a methodology for assimilation of snow data, using the historical interrelationships among model internal states to determine how, if at all, other non-snow model states need to change.

If it is necessary for the recent hydrograph to match the near-term forecast, another possibility is to perform a statistical time series analysis of recent errors and apply a bias correction to the near-term forecast to make them align. The MIKE-SHE European hydrologic model (Refsgaard and Storm, 1995) allows the user to automatically deconstruct the recent errors into bias, magnitude, and timing, generating a time varying correction function into the future. This correction may add to the plausibility of the forecasts by giving the user the (potentially false) impression that the model is simulating basin conditions accurately, but it is simply treating the “symptoms” of what could be a more serious underlying “disease.”
If a model contains unavoidable systematic biases, it may be useful to apply statistical post processing to ensure the optimal translation of model output into forecast information. This may involve, for example, converting a model forecast volume for each hydrograph trace into a percentile ranking with respect to the model climatology during calibration. This percentile is then converted into a volume with respect to the observed historical streamflow value. Other options include the fitting of model simulated and observed streamflows to statistical distributions to estimate the adjustments necessary to the forecasts. No specific technique for such bias adjustment has emerged as a clear favorite; the NWS Colorado River Basin River Forecast Center system allows the operator to fit no fewer than 5 different distributions to the historical and real-time data and has multiple error models available to post process the data. With bias adjustment, however, one must operate from the assumption that even though the model got the historical simulation “wrong,” the relative change in the model forecast relative to the model climatology was the “right” forecast of real conditions. The relevance of historical model errors to the real-time forecast errors also diminishes if real-time adjustments are made to the model (e.g., snowpack assimilation, manual changes to model states) that weren’t made during the historical model runs.

Finally, standard ESP assumes that all meteorological sequences (traces) are equally likely and therefore receive an equal weighting when deriving products (e.g., the simple average of the output traces as opposed to a weighted average). However, it is possible to indicate that, for example, if an El Niño event is underway, that the anticipated meteorological sequence is more likely to resemble other El Niño years than the opposite, La Niña years. Therefore, El Niño year traces should receive a heavier weight in output products than La Niña year traces. Werner, et al., (2004) has tested 6 climate-based trace weighting schemes for use with the NWS model. Clark, et al., (2004) has also probabilistically integrated long-term meteorological (i.e., 10-15 day) forecasts into ESP. Climate change such as regional warming may make some scenarios less relevant than others. Ideally, the NRCS hydrologic forecast should be consistent with the variety of other climatological and meteorological forecasts that exist across a range of temporal scales. As earlier, the science of trace weighting seems robust and the ability to incorporate this information will ultimately depend on the resources available to the agency.

**Summary and Conclusions**

Continuing a long-standing interest in the use of hydrologic simulation models for operational water supply forecasting, the NRCS has developed a preliminary prototype based on the PRMS/MMS system. As of 2005, 2 parameter sets each have been created for 16 basins across the western United States, without using any manual calibration. Data is retrieved daily from the SNOTEL and ACIS networks and is automatically processed for model ingestion. The time required to gather data, and run the model for all basins and all parameter sets is approximately 15 minutes on an ordinary desktop computer and can be done on a scheduler with no human intervention. Many scientific and technical challenges remain including, but not limited to, issues related to data quality, database design, data assimilation, uncertainty estimation, pre- and post-processing, and effective delivery and communication of results. The agency aims to build an infrastructure that is robust yet flexible enough to accommodate new developments within the research community.

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Snow Modeling and Observations at
NOAA’S National Operational Hydrologic Remote Sensing Center

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Abstract

The National Oceanic and Atmospheric Administration’s (NOAA) National Operational Hydrologic Remote Sensing Center (NOHRSC) routinely ingests all of the electronically available, real-time, ground-based, snow data; airborne snow water equivalent data; satellite areal extent of snow cover information; and numerical weather prediction (NWP) model forcings for the coterminous United States. The NWP model forcings are physically downscaled from their native 13 kilometer² (km²) spatial resolution to a 1 km² resolution for the coterminous United States. The downscaled NWP forcings drive the NOHRSC Snow Model (NSM) that includes an energy-and-mass-balance snow accumulation and ablation model run at a 1 km² spatial resolution and at a 1 hour temporal resolution for the country. The ground-based, airborne, and satellite snow observations are assimilated into the model state variables simulated by the NSM using a Newtonian nudging technique. The principle advantages of the assimilation technique are: (1) approximate balance is maintained in the NSM, (2) physical processes are easily accommodated in the model, and (3) asynoptic data are incorporated at the appropriate times. The NSM is reinitialized with the assimilated snow observations to generate a variety of snow products that combine to form NOAA’s NOHRSC National Snow Analyses (NSA). The NOHRSC NSA incorporate all of the information necessary and available to produce a “best estimate” of real-time snow cover conditions at 1 km² spatial resolution and 1 hour temporal resolution for the country.

The NOHRSC NSA consists of a variety of daily, operational products that characterize real-time snowpack conditions. The products are generated and distributed in a variety of formats including: interactive maps, time-series, alphanumeric products (e.g., mean areal snow water equivalent on a hydrologic basin-by-basin basis), text and map discussions, map animations, and quantitative gridded products. The NOHRSC NSA products are used operationally by NOAA’s National Weather Service field offices when issuing hydrologic forecasts and warnings including river and flood forecasts, water supply forecasts, and spring flood outlooks for the nation. Additionally, the NOHRSC NSA products are used by a wide variety of federal, state, local, municipal, private-sector, and general-public end-users with a requirement for real-time snowpack information. This paper discusses, in detail, the techniques and procedures used to create the NOHRSC NSA products distributed over the NOHRSC Web site (www.nohrsc.noaa.gov).
Introduction

Snow has substantial impacts on human behavior and activity across the nation and, consequently, has important economic consequences. Generating, distributing, and using snowpack information in the decision making process has economic value, or benefits, because of the potential to increase positive impacts or decrease negative economic impacts associated with snow cover conditions. For example, in the western United States spring snowmelt provides over 70 percent of the water supply. It has been estimated that the water supply derived from spring snowmelt is worth in excess of $348 billion per year on average. Additionally, snow also plays a significant role in the U.S. tourism economy estimated to exceed $7.9 billion dollars per year. The average cost of snow removal for streets and highways in the United States exceeds $2 billion annually. In New York City alone, the cost of snow removal is estimated to be $1 million per inch of snow depth. The single 1997 snowmelt flood that impacted Grand Forks and the Red River of the North caused in excess of $5 billion dollars of damage.

Enhanced, accurate, near real-time information on snowpack conditions across the country is critical for managers and others to make optimal decisions required to support river, flood, and water supply forecasting; agriculture and forest management; recreation and winter tourism; and the commerce, industry, and transportation sectors of the nation’s economy. As a result of the critical importance of snow and snow information to the nation’s economy, it has been estimated that improved information on snowpack conditions has “potential benefits greater than $1.3 billion annually” for the country (Adams, et al., 2004).

To help capitalize on these potential benefits, the U.S. Department of Commerce’s NOAA maintains the NWS NOHRSC site in Minneapolis, Minnesota. The NOHRSC uses advanced snow data collection and modeling technology to generate daily and hourly gridded NSAs at high spatial resolution (1 km²) for the country. The NSA products and data sets use ground-based, airborne, and satellite snow observations coupled with numerical weather prediction model forcings to drive an energy-and-mass-balance snow model. In this way, all available snow information is used to generate the “best estimate” of snowpack characteristics across the country. The NOHRSC NSA products and data sets are used by the NWS, other government agencies, the private sector, and the public to support operational and research hydrology programs across the nation. The NSA products and data sets include estimates of: snow water equivalent, snow depth, snowpack temperatures, snow sublimation, snow evaporation, estimates of blowing snow, modeled and observed snow information, airborne snow data, satellite snow cover, historic snow data, and time-series for selected modeled snow products.

Operational Data Processing

The NOHRSC ingests daily ground-based, airborne, and satellite snow observations from all available electronic sources for the coterminous U.S. These data are used along with estimates of snowpack characteristics generated by a physically-based snow model. The NOHRSC Snow Model (NSM) is an energy-and-mass-balance, spatially-uncoupled, vertically-distributed, multi-layer snow model run operationally at 1 km² spatial resolution and hourly temporal resolution for the nation. The model has run continuously at hourly time steps since the 2001-2002 snow season — first in an experimental mode, and since the 2004-2005 snow season, in an NWS operational mode. Ground-based and remotely sensed snow observations are assimilated daily.
into the simulated snow-model state variables. NOHRSC NSA output products are distributed in a variety of interactive maps, text discussions, alphanumeric, time-series, and gridded formats. NSA product formats include: (1) daily national and regional maps for nine snowpack characteristics, (2) seasonal, 2-week, and 24-hour movie-loop animations for nine snowpack characteristics, (3) text summaries, (4) a suite of interactive maps, text, and time-series products, (5) selected hourly and daily gridded snow products for the continental United States excluding the states of Alaska and Hawaii (CONUS), and (6) 3-D visualization products suitable for viewing with KML interpreters (file format used to display geographic data in an Earth browser) such as Google Earth. The NSA provide information about snow water equivalent, snow depth, surface and profile snowpack temperatures, snowmelt, surface and blowing snow sublimation, snow-surface energy exchanges, precipitation, and weather forcings all in multiple formats.

A variety of data sets are ingested daily at the NOHRSC and include ground-based snow water equivalent and snow depth data from the Natural Resources Conservation Service (NRCS), the California Department of Water Resources, British Columbia Ministry of Environment, U.S. Army Corps of Engineers, NWS cooperative observers, and other mesonet sources. Each day, the office ingests, processes, and archives all snow data available from 25,000 reporting stations across the United States and southern Canada. Each snow season, the NOHRSC makes approximately 1,500 to 2,500 airborne snow water equivalent measurements that are assimilated into the NSA. Additionally, the office ingests the full spectral and spatial resolution Geostationary Operational Environmental Satellite (GOES) East and West image data four times each hour. Six passes of Advanced Very High Resolution Radiometer (AVHRR) data are ingested daily by the NOHRSC NOAA Polar Orbiting earth receive station. The GOES and AVHRR satellite data sets (and eventually, MODIS) are used to infer areal extent of snow cover over the coterminous United States. The AVHRR image data are used to generate daily fractional snow cover maps for the CONUS and Alaska. Numerical Weather Prediction (NWP) model data (i.e., Rapid Update Cycle [RUC2], Eta model, Mesocale Analysis and Prediction System [MAPS]) and Next Generation Radar (NEXRAD)-derived precipitation estimates for the coterminous United States are ingested daily and used to drive the physically based NSM (Carroll, et al., 2001).

Ground-based, airborne, satellite, numerical weather prediction (NWP) model, and radar data for the country are ingested daily at the NOHRSC (Figure 1). The data are pre-processed, quality controlled, archived, and used in the NOHRSC Snow Model. A variety of products are generated in multiple formats for distribution to end users.

The NOHRSC Snow Model (NSM)

Because snow water equivalent observations are not sufficient in time or space across the coterminous United States to infer reasonably the distribution of snow water equivalent, it is helpful to model the snowpack using available NWP model output data sets as input to a fully distributed, energy-and-mass-balance snow model (Cline, 1997a, 1997b). Consequently, the NOHRSC developed the NSM to simulate, in near real-time, snow water equivalent and other snowpack properties, for the coterminous United States. The NSM consists, essentially, of three components: 1) data ingest, quality control, and downscaling procedures, 2) a snow accumulation and ablation model, and 3) snow model data assimilation and updating procedures.
Hydrometeorological observations and NWP output are used to force the NSM, run at 1 km² resolution, for the country (Figure 2). Furthermore, after the model is initialized, periodic (or sometimes daily) observations of snow water equivalent, snow depth, and areal extent of snow cover are assimilated into the modeled snow states at the appropriate time step.

Figure 1. National Operational Hydrologic Remote Sensing Center Operations.

Figure 2. The NOHRSC snow model.
The NOHRSC snow model uses hourly NWP model output products and static data sets as input. The model includes an energy-and-mass-balance snow model, a blowing snow model, and a radiative transfer model. Unadulterated model output (i.e., snow water equivalent and snow depth) are compared to available snow observations, differences are calculated, the model is reinitialized to include information from snow observations, and final products are generated.

The NSM is an energy-and-mass-balance, spatially-uncoupled, vertically-distributed, multi-layer snow model. The NSM incorporates the mathematical approach of Tarboton and Luce (1996) to address the snow surface temperature solution and that of Jordan (1990) to address the snow thermal dynamics for energy and mass fluxes as represented in SNTHERM.89 (a one-dimensional mass and energy balance model of snow and frozen soil). It accounts for the net mass transport from the snow surface to the atmosphere by sublimation of the saltation-transported and suspension-transported snow as developed by Pomeroy, et al. (1993).

The NSM is forced by hourly, 1 km², gridded, meteorological input data downscaled from mesoscale NWP Rapid Update Cycle (RUC2) model analyses with the three major-layer state variables of water content, internal energy, and thickness. It generates total snow water equivalent, snowpack thickness, and energy content of the pack along with a number of energy and mass fluxes at the snow surface and between the snow and soil layers.

Development of the NSM was motivated by the need for moderate spatial resolution (~1 km) commensurate with operational, optical, remote sensing data sets (i.e., GOES and AVHRR) used to update the model. Additionally, high temporal resolution (hourly) is required to provide adequate representation of the physical processes in shallow snowpacks. These spatial and temporal resolution requirements for the coterminous United States demand computational efficiency by the model. The current multi-layer snow model is moderately comprehensive with a strong physical basis. It requires only a few input state variables, is parsimonious and efficient in computation, and is appropriate for representing most prevailing snowpack conditions.

Snow Model Data Input

The NSM is driven with gridded estimates of air temperature, relative humidity, wind speed, precipitation, incident solar radiation, and incident longwave radiation (Figure 3). Surface meteorological data are acquired by the NOHRSC from manual and automatic weather stations. Most of these data are in METAR format (international standard format for hourly surface weather observations) and are decoded, quality controlled, and inserted into the NOHRSC Informix database. Additional surface meteorological data are acquired from sources such as the NRCS Snow Telemetry (SNOTEL) system and from NWS cooperative observers. The meteorological driving data for the NSM are generated by downscaling gridded NWP model analysis products from the RUC2 developed and supported by the NOAA Forecast Systems Laboratory (FSL) in Boulder, Colorado (Miller and Benjamin, 1992). If, for some reason, the RUC2 data are temporarily unavailable, the system is capable of ingesting automatically the companion FSL Mesoscale Analysis and Prediction System (MAPS) data sets. The National Environmental Satellite, Data, and Information Service, NOAA, currently produces solar radiation products derived from the GOES imager and sounder data (Tarpley, et al., 1997) that are used by the NSM. The NSM also uses “static” gridded data such as digital elevation data and
associated derivatives of slope and aspect, forest cover, and forest type information derived from remotely sensed data, and soils information (Figure 3).

**Figure 3. NOHRSC snow model data input.** The gridded data input are physically downscaled from the 40 km NWP model resolution to 1 km² required by the NSM. Ground-based point observations are automatically quality controlled, used in downscaling, and ingested by the NSM.

The mesoscale RUC2 atmospheric model output variables are downscaled, using a 1 km² digital elevation model (DEM), from the native 13 km resolution to the 1 km² resolution required by the NSM. The NOHRSC downscaling procedures are currently capable of processing higher resolution NWP model output fields as they become available (Carroll, et al., 2000).

**NOHRSC Snow Model Updating**

Observations of snowpack properties (e.g., snow water equivalent and snow depth) are used to update the NSM state variables. The NOHRSC ingests point data from over 25,000 reporting stations in the coterminous United States. Of those 25,000 stations, approximately 10,000 report snow data during the course of the season. Table 1 provides the complete summary of the NSM input and output variables. A clear advantage to the NSM modeling approach is that all of the available data — ground-based, airborne, satellite, and NWP model data sets — are used to generate the “best estimate” of a gridded snow water equivalent field at 1 km² resolution for the country. Consequently, this approach provides the opportunity to capitalize on the comparatively plentiful ground-based snow depth data heretofore of limited use in NWS operational hydrologic modeling.

Ground-based and airborne observations of snow water equivalent are used to update the NSM water equivalent state variable. Additionally, the comparatively plentiful snow depth observations made by cooperative observers are used to update the snowpack thickness state.
variable. Satellite areal extent of snow cover is used to update the presence or absence of snow cover.

Rasters for each of the model state variables (Figure 4 and Table 1) snow water equivalent, snow depth, snow temperature (both internal and snow surface), and change in snowpack heat content, etc., and the relevant meteorological driving data can be made available to end users upon request. The most appropriate and effective methods for the four-level discrete dipole approximation (4DDA) system, an atmospheric model, remain to be determined and are the subject of current research activities at the NOHRSC.

**NOHRSC Snow Model Results and Conclusion**

NOHRSC NSA products are generated daily and distributed over the NOHRSC Web site (www.nohrsc.noaa.gov). The gridded products are shipped in near real-time to the National Snow and Ice Data Center in Boulder, Colorado, and to the NOAA National Climatic Data Center in Asheville, North Carolina, where they are archived and distributed to end users upon request. NSA products include information in multiple formats on snow water equivalent, snow depth, surface and vertical average snowpack temperature, snowpack surface condensation and sublimation, blowing snow sublimation, and snow melt.

The NOHRSC snow model is a physically-based, energy-and-mass-balance snow model for a three-layer snowpack with two layers of soil below. It is run with a horizontal resolution of 1 km. Input data are primarily outputs from the RUC2 model, scaled from the model’s intrinsic 13 km resolution to the required 1 km² resolution. The primary driving (input) variables for the model are surface air temperature, relative humidity, vector winds, precipitation (snow and non-

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Figure 4. NOHRSC snow model update data sets. Ground-based and airborne snow water equivalent data are used to update the NSM. Snow depth and satellite-derived areal extent of snow cover observations are also used to update the model.

snow), and solar radiation. The primary state variables (input/output) of the model are snow water equivalent, snowpack thickness, and snowpack internal energy. The initial snow water equivalent required by the model (when initialized in the middle of the snow season) is generated by interpolating point observations of snow water equivalent and snow depth. The initial internal energy is inferred from daily temperature data.

The snow modeling and observed snow data assimilation approach adopted by the NOHRSC has the advantage of maximizing all of the information provided by near real-time NWP model forcings as well as all electronically available snow observations. In this way it is possible to generate a “best estimate” of snowpack characteristics using: (1) state-of-the-art snow model physics, (2) NWP model forcings, and (3) all available ground-based, airborne, and satellite snow observations. Resulting NOHRSC NSA products are generated in a variety of formats including: interactive map, animation, time series, gridded, text discussions, flat file, and 3-D visualization. The NOHRSC NSA products are used by a wide variety of federal, state, local, municipal, private-sector, academic, and general public end users. The critical nature and importance of the NOHRSC NSA products is reflected in the fact that after a major snow storm, the NOHRSC Web site can receive over 1 million hits in a single day.

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Overview of Management of Natural and Environmental Resources for Sustainable Agricultural Development in France

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Abstract

Agriculture plays an important and double role in environmental and natural resources. Agriculture contributes to degradation but at the same time can help to preserve and restore resources. In France and in many other countries, intensive cultural practices have contributed to soil and water degradation (pollution, acidification, erosion). With climate change and the increase of natural disasters, degradation will become a major problem in the next few years. In France, some measures have been taken for agriculture with the installation of the Sustainable Agricultural Contract (Contrat d’Agriculture Durable or CAD) that farmers sign with government. At the same time, tools for monitoring and forecasting main risk factors have been developed for better management and protection of natural and environmental resources.

Introduction

Soils comprise one of the three components of the biosphere along with water and the atmosphere that are essential for biological activity and earth biodiversity. They have many functions that can be modified because of natural factors but also from human activities such as agricultural and industrial development. Disruptions of the natural balance can produce long-term degradations in soils, (pollution, erosion, acidification, salinization), water (pollution, eutrophisation), and atmosphere (pollution, disasters). In France, soil and water are sources of concern. Pollution, the heat wave in 2003, and drought in 2005, have raised awareness of the value of water. Natural resource degradations, and recent natural disasters (storms, floods) with potential consequences of climate change, have begun to be taken into account both at a citizen and a political scale and have resulted in protection, restoration, and monitoring of environmental resources measures.

Agriculture is one of the causes but also is directly and indirectly impacted by natural and environmental resources degradation. It is a system that must be taken into account. Sustainable agricultural development is an essential point in the natural resources preservation. Integration of environmental problems in the European Union (EU) Agricultural Policy (Common Agricultural Policy - CAP) demonstrates the importance of the subject.

Environmental Resources and Natural Disasters

The rural landscape represents 95 percent of the total area in France of which 59 percent is agricultural and 26 percent is covered in forests. From 1990 to 2000, grassland has been reduced by 0.8 percent of arable land. In 2003, artificial surfaces (man-made surfaces such as roads, houses, etc.) occupied 8 percent of the territory. Between 1993 and 2003 artificial surfaces increased by more than 15.6 percent, mainly to the detriment of agricultural land and natural
areas (IFEN, 2005). Very often this use of artificial surfaces is an irreversible alteration of soils that contribute to the reduction of biodiversity.

**Soil Degradation**

Soil degradation is an important issue for sustainable agricultural development. The loss of soil function effects the environment, both on a local scale (erosion, decrease of fertility, pollution), and on a large scale (reduction of the biodiversity). Soil quality has deteriorated over the last few decades, in particular in the countries affected by desertification and drought. The situation is also of concern in Europe, even if there are some regional differences. Without giving a review of the different types of soil degradation, some significant examples can show the dimension of this problem in France.

**Loss of Organic Matter**

Many studies have shown that organic matter rates in the soil seem to decrease in some areas of France. It is the case, for example, in Bretagne (western France) where there has been a decrease of about 0.5 percent of the organic matter rate during the last 25 years in soils where the initial rate was about 3 percent and a decrease of more than 1 percent in soils where the initial rate was about 7 percent. This is a concern because this decrease can have important environmental consequences on soil fertility, erosion, runoff, and leaching.

**Soil Acidification**

Soil acidification is part of the consequence of changes in agricultural practices such as the reduction of lime spreading and intensification of agriculture (increasing of nitrogen contents, decreasing of organic matter).

In France, this is especially a problem for forests in the Southwest and Northeast. During the 1970s, the yellowing of tree leaf was observed. Sulfur atmospheric deposits were thought to be indirectly responsible because of acidifying effects on soils and water. Consequences of this acidification were the withering of trees, a decrease of soil fertility, erosion resistance, biodiversity, and an eutrophisation of rivers. Nonetheless, this eutrophisation concerns almost all of France: it is estimated that 90 percent of the area of France has atmospheric deposits that cause or will cause the eutrophisation of ecosystems. A study has shown in 1995 that 90 percent of rivers in the Vosges (eastern France) had some degradation because of acidification (Le Gall, 2004).

**Soils Erosion**

The erosion risk in France is medium to high (Figure 1). Taking into account the erosion in environmental and sustainable agricultural policy is a priority because of its irreversible nature. The main factors for water erosion are the soil and its utilization, topography, and climate. In France, there are four main types of erosion in function of the release factors (Le Bissonais, et al., 2003):
- erosion in large scale farming;
- erosion in vineyards and orchards;
- mountain erosion;
- Mediterranean coastal erosion.

Erosion brings about destruction of seedlings, loss of soil capital and fertility, and increased potential of mudslides. On a large scale, erosion also causes water pollution. Runoff is loaded with suspended matter carrying chemical components (phytosanitary products) that increase river turbidity and their content of eutrophisant products.

![Annual soil erosion risk in Europe.](image)

Figure 1. Annual soil erosion risk in Europe.

It is difficult to characterize quantitatively the erosive hazard. But the increased risk (defined as the product of hazard and vulnerability) is more probable. There are multiple agricultural reasons for this: the removal of hedges and ditches to extend the parcel, specialisation of crops, and reduction of grass areas. The erosion risk in France has been modelled and mapped by the French Institute for Agronomical Research – INRA (Figure 2).

The model is composed of three stages:

- Evaluation of the potential suitability of land, established from soils, slopes, and uses data;
- Evaluation of the average and seasonal risk by geographic unit (district, watershed, agricultural area) established with the potential suitability and seasonal rainfall;
- Topological zoning of the risks to localize the different types of erosion.
Water Resource and Agriculture

Water management is also a big factor for sustainable agricultural development. In France, water consumption from agriculture is 30 to 40 percent of the total consumption but in the summer it can reach about 80 percent and 90 percent in the south of France. Irrigated areas have increased over the last few years: 0.5 million hectares (ha) in 1970, 1.1 million ha in 1998, and 1.8 million ha in 2003. A succession of more or less severe drought during the last 3 decades (1976, 1979, 1985, 1986, 1989, 1990, 1991, 2003, and 2005) can explain this development. Until 2003, EU agricultural policy (CAP) had encouraged irrigated production to increase productivity. But the new CAP removes or limits subsidies for irrigation. In the short term, this should lead to decreasing the total irrigated area by about 10 percent, 14 percent for corn, and water consumption in France should also decrease by about 7 percent (MEDD, 2005).

But conflicts about use of water resources are more and more frequent, in particular in 2005, where the legitimacy of irrigated corn was especially questioned. With climate change scenarios that predict a temperature increase of about 3 to 5°C in summer and at the same time a rainfall decrease of 0.1 to 1 millimeter (mm) per day, the issue of water resources will be crucial, in particular for agriculture.
**Extreme Natural Events**

**Floods**

Flood hazard is a concern in about 5 to 7 percent of the area in France, and 10 percent of the French population live in this area where the flood hazard is significant. Floods are the main risk in France and cause 75 percent of the damages (on average and financially). The average annual cost of the floods is from about 600 million Euros, and the number of floods has increased over the last few years (Figure 3 and Table 1).

![Figure 3. Indemnities paid by insurance companies for floods in France since 1992 (not adjusted for inflation).](image)

**Table 1. Major floods in France.**

<table>
<thead>
<tr>
<th>Date</th>
<th>Location</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1875</td>
<td>South West</td>
<td>200 deaths</td>
</tr>
<tr>
<td>1910</td>
<td>Center (Paris)</td>
<td></td>
</tr>
<tr>
<td>1930</td>
<td>South West</td>
<td>More than 300 deaths, 10 000 disaster victims</td>
</tr>
<tr>
<td>1940</td>
<td>South West</td>
<td>300 deaths</td>
</tr>
<tr>
<td>1958</td>
<td>South East</td>
<td></td>
</tr>
<tr>
<td>1977</td>
<td>South West</td>
<td>5 deaths</td>
</tr>
<tr>
<td>1983</td>
<td>South West</td>
<td>5 deaths</td>
</tr>
<tr>
<td>1987</td>
<td>Alpes</td>
<td>23 deaths</td>
</tr>
<tr>
<td>1988</td>
<td>South East (Nîmes)</td>
<td>11 deaths, 150 million Euros of damage</td>
</tr>
<tr>
<td>1990</td>
<td>West end East</td>
<td>180 million Euros of indemnity</td>
</tr>
<tr>
<td>1992</td>
<td>South East (Vaison)</td>
<td>41 deaths, 150 million Euros of damage</td>
</tr>
<tr>
<td>1993-94</td>
<td>North</td>
<td>21 deaths, 530 million Euros of damage</td>
</tr>
<tr>
<td>1994</td>
<td>South East (Nice)</td>
<td>120 million Euros of indemnity</td>
</tr>
<tr>
<td>1995</td>
<td>North</td>
<td>400 million Euros of indemnity</td>
</tr>
<tr>
<td>1997</td>
<td>West</td>
<td>65 million Euros of damage</td>
</tr>
<tr>
<td>1999</td>
<td>South West (Aude)</td>
<td>34 deaths, 650 million Euros of indemnity</td>
</tr>
<tr>
<td>2001</td>
<td>North</td>
<td>40 million Euros of damage</td>
</tr>
<tr>
<td>2002</td>
<td>South East</td>
<td>23 deaths, 1.2 billion Euros of damage</td>
</tr>
</tbody>
</table>
The increase in flood damage can be explained by urban development through the increase in artificial surfaces (see previous section) but also by changes in agricultural practices. For example, it was estimated that if the 1905 flood of Seine River should happen again, the cost would be about 10 billion Euros, versus 1.4 billion in 1910.

**Storms**

Storms are very destructive for agriculture and especially for forestry. As for floods, it seems that number of storms has increased over the 2-3 decades (Table 2).

<table>
<thead>
<tr>
<th>Date</th>
<th>Millions Euros</th>
</tr>
</thead>
<tbody>
<tr>
<td>January 1976</td>
<td>41</td>
</tr>
<tr>
<td>December 1979</td>
<td>32</td>
</tr>
<tr>
<td>November 1982</td>
<td>440</td>
</tr>
<tr>
<td>February 1984</td>
<td>65</td>
</tr>
<tr>
<td>July 1984</td>
<td>126</td>
</tr>
<tr>
<td>October 1984</td>
<td>15</td>
</tr>
<tr>
<td>November 1984</td>
<td>45</td>
</tr>
<tr>
<td>December 1987</td>
<td>500</td>
</tr>
<tr>
<td>January 1990</td>
<td>990</td>
</tr>
<tr>
<td>February 1990</td>
<td>1 330</td>
</tr>
<tr>
<td>December 1999</td>
<td>11 500</td>
</tr>
</tbody>
</table>

The storm of December 1990 caused the death of 92 people and 130 million trees (132 billions m$^3$ of wood) were uprooted.

**Impacts of Climate Change**

During the last century, the temperature has increased in some areas of France up to +0.9°C and +1.5°C for maximum and minimum average temperature, respectively. Already some signs of this warming are observable, for example, in the case of the phenology of fruit trees and vines (Seguin, 2003). Several studies showed an advanced onset of vegetation since 1970 (Figure 4).
For forestry, studies showed an acceleration of tree growth since the beginning of the 19th century that can be connected with the elevation of CO2 in atmosphere (Figure 5).

A consequence of climate change can already be observed in regards to bird migration. This is very important for agriculture and especially for breeding because birds are direct or indirect vectors of pathogen agents:

- birds carry ticks and associated bacteria (Borrelia burgdorferi: Lyme);
- their blood can carry viruses (West Nile, etc.);
- bacteria are in their excrement (Chlamydia, Campylobacter);
- nasal secretions can carry viruses (Influenza)
For example, the migration of birds to Heligoland Island (Northern Germany) takes place 2-12 days earlier than 40 years ago. In the United Kingdom, Sparks (1999) found an advance of 1 to 2 days in the arrival of swallows per 1°C mean temperature increase and observed that:

- short migrations take place on average 1 to 4 days earlier every 10 years;
- date of egg laying is earlier;
- there is an increase of second egg laying;
- the area of southern species has moved 10 kilometers (km) northward over the last 20 years.

In the future, with response to climate change, ecosystems in France will change. Using climate change scenarios for the end of the 21st century, a map of the natural tree areas show some important modifications, with an increase of holm oak and maritime natural pine areas and a decrease of fir and chestnut (Figure 6).

On plant ecophysiology, consequences could be:

- an increase of photosynthesis activity and of biomass production;
- an acceleration of phenology (shorter cycles);
- better water efficiency.

![Figure 6. Natural trees areas in France in 1980 and estimated for 2100.](image)
Public Policies and Services for Environmental Managers

*Sustainable Agriculture Contract*

The Sustainable Agriculture Contract (Contrat d'Agriculture Durable or CAD in French) was created in 2003 by the government to develop the various facets of French agriculture. Its aim is to increase farmer contribution to natural resources protection, rural development; and the goals are erosion mitigation, preserving soil quality, water resources, biodiversity, and landscapes.

Contracts are between farmers and the government for a period of 5 years. The contracts have two sections:

- the first is an optional socio-economic section. The upper limit is fixed at 15,000 Euros, and is to help the farmer transition to a sustainable agriculture (diversification of activities and productions, and an improvement in the quality of products);
- the second, which is obligatory, is an agro-environmental section. It pays for additional costs and loss of income resulting of the use of best practices for environment.

The CAD responds to regional problems and agro-environmental actions are adapted for each French area. In 2004, 234 million Euros have been paid and about 10,000 contracts have been signed.

*Tools for Risk Monitoring and Evaluation*

*Monitoring of Hydrological Conditions*

Since 2004, the French National Weather Service (Meteo-France) has maintained daily monitoring of water and energy balances and water flows of the main watersheds. This information is used for several diagnostic or forecast applications. For example, the soil water index (SWI) is estimated to characterize drought conditions.

\[
\text{SWI Index} = \frac{(w - \text{wilt})}{(\text{wfc} - \text{wilt})}
\]

With
- \( w \) : water in soil
- \( \text{wfc} \) : field capacity
- \( \text{wilt} \) : wilting point

*Assistance for Wildfire Surveillance*

Since 1965, more than 1 million hectares (ha) of forest land have burned in France. The average area burned each year by wild fire is about 26,000 ha, but in 2003, with the heat wave, there was more than 70,000 ha burned (Figure 7). Wildfire increases soil degradation, reduces biodiversity, and increases erosion risks. Meteo-France provides emergency services and meteorological assistance for wildfire prevention in southern France. This monitoring is based on the daily expertise of meteorological conditions and the forecast of the drought index. The risk is divided into six levels: exceptional, very severe, severe, moderate, light, and weak.
**Tools for Agriculture and Irrigation**

At the Agriculture Ministry's request, Meteo-France with the French National Institute for Agricultural Research (INRA), the agricultural technical institute and water management service, provides maps for assessment of the water needs for irrigated corn. This information is used during droughts to adopt the water restriction measures in each agricultural area.

**Conclusion**

Natural and environmental resources degradation in France do not have the same consequences as in arid countries, however the situation is of concern in particular because of the increasing number and intensity of problems. This degradation is all the more worrying in that the effects of climate change are increasing and will continue to do so. Agriculture is both victim and responsible for the situation. By employing the best agricultural practices, some problems could be resolved. Public measures such as the CAD and assessments of risk and need are also important to develop a sustainable agriculture.

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References


Land Degradation

and

Natural Disaster Reduction
Trends in Land Degradation in South America

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Abstract

This paper gives a brief introduction to various land degradation processes. It then gives an overview of the trends in land degradation in Chile and other South American countries. An important tendency of agriculture has been the conversion of traditional cultivations like beans and corn to new export cultivations, in particular soybeans and sorghum. Observers have noticed an obvious relationship in deforestation that has occurred in the region with the increase of pasturelands for cattle raising. Erosion that constitutes one or more serious forms, including the generalized degradation of soils in the region, can be verified, and has increased in recent decades due to uncontrolled expansion of cattle raising at unapt zones and the extension of agriculture to zones of slopes where freak erosion occurs. In particular certain countries have experienced grave characteristics, including the abandonment of extended areas. The principal problems of degradation of the soil that affect the southern region of South America are: water erosion, wind erosion, advance of dunes, extraction of soil, salinization, problems of drainage, fertility loss, acidification, soil compaction, loss of structure, biological degradation, desiccation of fertile plains, landslides, and irreversible changes in the soil use. One of the environmentally important problems of the region is associated with the expansion of the cattle economy and the resulting conversion of soils from growing traditional crops to livestock feed crops (soybean and sorghum) and the conversion of forests to pasture lands.

State of Land Degradation Trends in Chile

From the agro-forestry point of view, land degradation basically refers to processes triggered by the human activities that reduce the actual and/or future capability of land to produce foods and goods of vegetable and animal origin. More specifically, land degradation refers to unfavorable alterations, either of physical, chemical or biological nature, of one or more of the soil properties. Unfortunately, due to inappropriate practices, human activity accelerates the rates of land degradation. It is estimated than around 2,000 million hectares in the world suffer some kind of deterioration as a consequence of man’s activities (Donoso, 1992).

The land degradation consists of the deterioration of soil quality and, logically, of its productive capability, which completely impedes plant functions. In general, degradation starts with the disappearance of the natural vegetation that covers the soil or with the freshly broken up ground. Both practices expose the soil to direct solar radiation and excessive oxygenation causing death to the living soil organisms. This then accelerates the biodegradation of the humus which causes aggregates to disappear and with them the porous soil that the humus generated. As a result, the water and air do not easily circulate, the soil surface gets compact and can even become impermeable, and water can run off the soil instead of becoming stored. The ultimate effect can be diminished crop performance and less profitable returns for the farmer.
The environmental deterioration that causes land degradation is inestimable and there are only general ideas of the damages that this phenomenon causes. For example, water erosion causes the loss of productivity that some authors have estimated in millions of dollars. The heavy environmental, productive, and economic costs associated with land degradation require private and public efforts to protect, preserve, and restore the soil, as well as monitoring this resource.

At the Thirteenth Session of the World Meteorological Organization’s (WMO) Commission for Agricultural Meteorology held in Slovenia in October 2002, a new structure, including expert teams, was agreed to and established. Among these was the Expert Team on the Management of Natural and Environmental Resources for Sustainable Agricultural Development, which was given seven basic tasks. One of these tasks was “To survey the status of, and summarize the information on, the trend in land at the national and regional levels.” It is within this mandate that this paper was written.

A request was sent to each member of the working group for Agricultural Meteorology of the WMO Regional Association IIII. Argentina, Bolivia, Ecuador, Paraguay, and Uruguay answered the request. In the case of Chile and other countries, this author provided the necessary information through contacts, literature review, and information and studies from organizations such as the United Nation’s Food and Agriculture Organization (FAO).

**Some Theoretic Aspects of the Processes of Degradation of Soils**

In developing countries, the increasing need of food and firewood have resulted in the deforestation and the cultivation of crops on highly sloping land, which has produced severe erosion. Further complicating the problem, it is necessary to take into account the loss of highly productive farmland due to the expansion of industry, cities, and roads. The over-exploitation of natural resources is the other main environmental problem that results from the combination of economic, social, and institutional factors. These problems have their origin in the over-exploitation of species with high commercial value, without taking the reproduction periods, size, and population into consideration and/or the unsuitable use of the soils for this production.

**Water and Wind Erosion**

Erosion is perhaps the one process of land degradation that causes the main impact, since it is often of great magnitude, irreversible and, in extreme cases, creates the total loss of soil. The erosive process is related to intrinsic soil properties such as texture, structure, stability of aggregates, and apparent density. Determining erodibility are the slope (grade, length, and form); rainfall (frequency, intensity, and duration); vegetation coverage; and the erosion control practices (Figure 1).
Figure 1. Factors that affect soil erosion.

Water erosion begins with the impact of the raindrop on the surface of the soil, which disperses the finest soil particles in many different ways and loosens the particles from the soil aggregates. The particles are thus separated, carried along by rainfall runoff, and once the soil capacity of infiltration is surpassed due to the intensity of the rain, this begins laminate erosion. When runoff becomes organized preferentially in little furrows, it increases its speed and kinetic energy, producing furrows (Figure 2); and is accompanied by landslides in the form of plates or displacements of a short distance without rupture of the surface, forming little perpendicular ridges to the slope. Finally, it can develop furrows and turn into trenches and ditches, with a total loss of the soil at the affected sector (Figure 3).

Where several furrows come together or integrate, ditches can form to a depth of over 30 centimeters (cm). The rate of the erosion of ditches depends on the characteristics of the basin: the size of drainage basin, characteristics of the soil, the sediments, the size and form of ditches, and the slope of the ditch.

Figure 2. Showing the formation of furrows.
Salinization

Salinization is another process of land degradation that generally derives from the use of saline waters of poor quality in crop irrigation without considering the impact of this saline water leaching through the soil. The worsening quality of soil is due to the accumulation of salts in the crop-root zone. This accumulation of salts prevents the plants from absorbing ground water and, therefore, reduces its growth and diminishes the biological productivity of the affected land.

Acidification

In agricultural land that is regularly cultivated with crops, frequent leaching of nutrients beyond the reach of the plants’ roots can happen. In the same way, a progressive decline of fertility can occur with an increase of acidity and toxic effects due to the alteration of the equilibrium among the soil chemical components. The main cause that limits the productivity when a certain level of “critical acidity” is exceeded is the toxicity of the aluminum that occurs in those conditions. An excess of aluminum decreases the absorptive capacity of water and nutrients by the plants and limits the growth and activity of roots.

Urbanization

The development of housing due to the growth of cities generally occurs on fertile soil. This development can cause the best agricultural soils to be lost, impeding the subterranean recharge of soil moisture and aquifers and destroy many microflora and microfauna that live in the soil. In many countries, a good portion of soils with high agricultural potential is found within urban limits, and fast urban growth is a threat to prime agricultural land.

Figure 3. Ditch formation in Navidad, Chile.
Pollution

Soils can also degrade when toxic substances accumulate in it over time. The FAO defines pollution as a form of chemical degradation that causes the partial or total loss of soil productivity. The accumulation of toxic substances is produced by artificial means as a consequence of human activities; but accumulation can also be caused by natural mechanisms that release substances contained in the rocks, allowing concentrates in the soil to reach toxic levels.

Soils possess a certain capability of withstanding human interventions without deteriorating. However, this capability has largely been surpassed in many places, as a consequence of the production and accumulation of industrial or urban use.

The pollution of soils also takes place due to the inappropriate removal and absence of treatment of human trash. The illegal dumping of industrial residues constitutes a serious problem of soil pollution.

State of Land Degradation Trends in Chile

In Chile, agriculture occupies a major place in the national economy, being an activity that occurs principally among the central and southern regions of the country. Among the natural resource sectors of Chile, agriculture ranked second in its contribution to the Gross National Product from 1996 to 2000.

Nearly 62 percent of the Chilean territory exhibits some form of soil erosion. Deforestation, improper irrigation, and the abuse of cultivation techniques have been an intrinsic characteristic in agriculture.

The large areas of eroded land in various forms and variable degrees of intensity that exist in Chile are related to the frailty of the ecosystems. One of the natural factors that affect the deterioration is the topography of hills and mountains that exist across most of the national territory.

The Andes Mountain Range is composed of igneous, sedimentary, and mixed rocks that were subjected to energetic physical processes and therefore caused erosive actions, which increased the transport of sediment towards a Central Depression. Theoretically, the Central Depression would have a physical character of ecological balance. Regardless of its flat topography, the unsuitable management techniques of soil and water resources tend to produce erosive processes of a certain magnitude in many sectors.

The physiographic position, the slope, and the original material of the soils are factors that have a marked influence on the erosive phenomena of the coastal mountain range. In general terms, the soils derived of igneous rocks display a greater degree of susceptibility to erosion. These soils have a clay subsoil of low permeability and a decomposed rock substrate with low cohesion (gravel), characteristics favoring runoff of surface water and the formation of active erosion gullies and channels (Peralta and Peralta, 1990). Most of these soils are found on
hillsides subject to intense grazing and removal of shrub vegetation. Hillside soils are generally used in seasonal agricultural production and have no plant cover for part of the year. On the other hand, soils derived from sedimentary materials do not generally show obvious signs of accelerated erosion.

The adoption of unsuitable agricultural practices in large rural sectors of the country has provoked a decrease of crop yields, an increase in production costs, a decrease in the wide use of soil options, an impoverishment of affected zone, and even increased migration of the population. In many zones, a vicious circle has developed between the increased soil erosion and the deepening of local poverty.

The Natural Resources Research Institute of Chile (1999), currently called the Information Center of Natural Resources, has made the only study that covers the entire continental territory of Chile. The study, which is entitled “Fragility of Natural Ecosystems of Chile,” was done to establish the situation of the soil and vegetation resources and to formulate a diagnosis of the soil erosion situation.

Land Degradation by Water and/or Wind Erosion

According to the Agricultural and Livestock Service (Spanish acronym SAG), 60 percent of the forest and agricultural area in Chile show moderate to very severe erosion. The most important problems of degradation by soil erosion in the agricultural-forestry sector is found in the altiplano sector, the foothills and mountains of the Andes in the Norte Chico coastal mountain range. Wind erosion is most pronounced in the semiarid steppes of Patagonia, where the soil remains dry for periods during intense spring and summer winds that easily remove and transport fine soil particles from the surface horizon.

Degradation of the Soils by Salinization

Salinization has been observed in many sectors of irrigated vineyards in the transverse northern valleys like Copiapó (Figure 4). In addition to these soils being degraded by machinery, they are also naturally saline or sodic due to climatic, topographic, and/or drainage reasons, therefore they tend to accumulate salts. Crops, especially fruit-bearing ones, do not tolerate high concentrations of salt or sodium, which will decrease the start of harvest, seed germination, and overall productivity.

Formation of Dunes

It is also necessary to mention the losses of agricultural soil and of biological potential produced by the action of dominant winds, which transport and produce accumulations of fine sands in the shape of dunes. According to a survey made at the beginning of the 1960s, Chile had about 74,500 hectares (ha) of coastal dunes between the central and south regions. In addition, there exist nearly 56,000 ha of continental dunes in the central-south region of Bio-Bio.
The coastal dunes in the country form, in general, to the north of the mouths of large rivers. This situation is caused by dominant coastal currents which move sands from a south to north direction discharged by the rivers, where waves deposit them on the beach. From there, the wind transports the sands and accumulates them in the form of dunes near the coast.

**Loss of Productive Soil Capacity Due to Mining-industrial Pollution**

In the majority of cases of soil pollution in the country, the toxic chemical substances come from mining and industrial activities. The soils receive residual materials emitted by these activities, generating a conflict of interest between mining and agriculture, mining and public health, and mining and environmental health.

The soil areas with high accumulations of copper are due to particulate material originating from the industrial sector. At close proximity to mining complexes, the concentration of this metal in the soil exceeds 100 times the natural content, which easily surpasses the maximum tolerance limit for plants. There are also accumulations of lead, arsenic, and cadmium, which entails serious risks for people’s health.

**Loss of Arable Soil Due to Urbanization and Change of Destination for Industrial Materials**

Due to the strong pressure to expand the urban limits of numerous cities in the center of the country, especially in regions V, VI, and Metropolitan Regions, proper attention has not been given to the urgent need to rationalize the use of soil resources that have a greater potential for agricultural activity.
State of Land and Degradation Trends at Regional Levels in South America

In South America, soil erosion is the main threat for land and this problem affects 68 percent of the land resources. Heavy rains and unsuitable agricultural practices on the slopes of hills and mountains are important causes in the loss of agricultural potential.

Deforestation has caused the degradation of about 100 million ha in South America, of which almost 70 million have been due to animal grazing. In the case of watersheds, deforestation is a key factor in the region. This process is very severe on western slopes (faldeo) of the Andes, where it principally affects tropical forests known as the “Yungas,” which extend from Colombia to Argentina.

In South America, it has been determined that the high environmental costs of agriculture are related to soil erosion, the loss of soil fertility, the degradation of lands by animal grazing, and excessive use of pesticides. Agriculture on unsuitable lands and/or with inappropriate techniques is characterized by a series of effects which includes:

- Increasing erosion of slopes due to deforestation, over-grazing, and inappropriate agricultural practices linked to both subsistence economies and large-scale business developments;
- Increase in the surface runoff and evaporation, reduced infiltration, and dramatic increase of erosion;
- Silting-up of rivers, diversion and impairment of river beds, and increased flooding frequency in the middle and lower courses during the rainy season;
- Drying-up of rivers and reduction of ground water during the dry season;
- Rapid silting up of reservoirs.

Soil degradation is also produced by the fragmentation of water systems, intense urbanization, uncontrolled pollution, and construction of large engineering projects, all fueled by an exponential growth of the human population and the lack of planning in the development process (Abramovitz, 1996; Comisión de Medio Ambiente, Desarrollo de America Latina, and el Caribe).

Current Situation of Soil Degradation in the Republic of Argentina

Due to its contribution to the economy and through the exportation of agricultural products such as grain and meat, agricultural production is the most important productive activity of the country. This traditional agro-export activity was the principal source of foreign exchange that financed the development of the country, and for many years it allowed for acceptable development. The agricultural sector continues to have a widely recognized importance in the Argentine economy.
Nevertheless, soil does not receive enough consideration since it supports Argentina’s agricultural activity. Almost 60 million ha are affected by water and wind erosion to either a moderate or severe level. Economic losses due to soil degradation are estimated to be nearly 700 million dollars per year.

The undulating landscape, intensity of the summer rains, low levels of water infiltration into the prevailing clay soils, and practice of conventional agriculture are the main causes of soil degradation. Many provinces are affected by this phenomenon.

The direct causes of wind erosion in the semiarid region are the lack of crop rotations, the reuse of inappropriate cultivation implements, over-grazing of natural and cultivated fields, deforestation of unsuitable lands for agriculture, and a common practice in this region, the tilling of unsuitable lands with ill-suited agricultural practices.

In the beginning of the 1990s, it was estimated that 20 percent of the national territory was affected by water and wind erosion (nearly 60 million ha). It has been estimated than each year between 200,000 and 650,000 ha of land are eroded (Casas, 2001).

Among the main causes of accelerated erosion in Argentina are the advance of the agricultural frontier on marginal lands without using the correct techniques; intensification of yearly cultivations without considering the aptitude of the land, conservation measures, and necessary management; uncontrolled elimination of vegetation, particularly deforestation; over-grazing of pasturelands; and deliberate and accidental fires.

Another important process at the national level is the physical degradation of soils as a result of excessive cultivation without crop rotation, improper handling of organic matter and agricultural waste, and inappropriate farming systems. The consequences are the creation of tillage pans, reduced infiltration, and increased risk of water erosion. These impacts are particularly severe in areas permanently under crops or under long-term rotation.

Soil salinization is also a serious problem in Argentina, affecting both irrigated and dry-farmed land. On irrigated land, the advance of salinization is widespread and accelerated primarily because of excessive irrigation in inappropriately drained areas or, in some cases, to the extraction of brackish groundwater. In several areas, over 60 percent of irrigated land has salinized soils.

Current Situation of Soil Degradation in Bolivia

Bolivia is a country with various geographic and ecological characteristics, offering a multiplicity of natural landscapes like high mountain glaciers, high plateaus, and valleys and plains with jungles and savannas. It possesses a great diversity of cultures, ways of life, and agroeconomic conditions.

The area affected by degradation covers 41 percent of the national territory and is mainly located in the Departments of Oruro, Potosí, Chuquisaca, Tarija, La Paz, Cochabamba, and Santa Cruz.
In Bolivia, the main environmental problem is land degradation, which is increasing and threatening, and is fundamentally expressed in an intense process of erosion that produces the loss of capability in agricultural and forest soils, the destruction of the productive base of the country, and the aggravation of poverty.

Bolivia is one of the more dramatic cases in the region. Between 1954 and 1996, the area of eroded soils increased from 236,833 kilometers (km$^2$) to 428,700 km$^2$, an increase of 86 percent according to official numbers (Benites, et al., 2003).

Official reports indicate that there is a systematic degradation of vegetation and forest coverage where people build urban settlements that do not meet minimal environmental sustainable requirements.

In addition to environmental implications, land degradation has serious economic consequences. Annually, 40 thousand ha of national territory lose productive capacity due to the effect of degradation. In addition to obvious environmental implications, this situation affects the economic development of the agricultural and forest sectors, which causes the loss of approximately 50 million dollars per year and represents 4 percent of the total output of the sector. According to data provided by land use and coverage maps, 82 percent is covered by pasture and forest lands susceptible to be used in more intense forms, which entails a potentially high risk of erosion and/or degradation of these ecosystems (Benites, et al., 2003).

The development of human settlements and the corresponding use of natural resources on steep slopes and semiarid climatic conditions have almost occupied all of these lands causing the disappearance of original forests in exchange for land preparation for agriculture, grazing, and firewood.

The continued use of the land has led to water erosion of the soil and to overgrazing. In some sectors of the Cochabamba valleys, irrigation and semiarid climate have generated salinization of soils. In these sectors, one encounters soil and water pollution due to mining activity.

**Conclusions for Bolivia**

- The different processes of soil degradation in Bolivia have taken place over large territories with advanced degrees of deterioration.
- Even though the impact of soil degradation on the Bolivian economy has not been quantified, it is evident that the there are very important socioeconomic outcomes like migration, increased costs in agriculture and infrastructure, and the systematic impoverishment of rural producers.
- Bolivia has extensive areas covered with forests and natural pasturelands in fragile environments with little management, which entails a high risk of increasing the area eroded by the advance of the present-day agricultural frontier.
- There does not exist a soil conservation service on a national scale, and what sources of information do exist are very dispersed and very local.
Current Situation of Soil Degradation in Brazil

In the country of Brazil, soil degradation began 4 centuries ago with the arrival of the Europeans and the first deforestations. This accelerated in the 19th century with the development of sugar cane and coffee plantations.

From the 1970s, the increased pace of export cultivations caused large soil degradation. In the 5 years from 1975 and 1980, Brazil moved into third place in the world among soybean producing countries by replacing subsistence or low-impact agriculture with highly mechanized agriculture. The acquisition of agricultural machinery increased 2,000 percent between 1975 and 1995 (Merten, 1996).

This trend greatly modified the biological activity of the soil, and it increased land erosion by four to five times. Today, the state of Sao Paulo loses 200 to 250 million tons of arable land per year, a number that would have to be multiplied by thirty to obtain a national estimate (Merten, 1996).

Cultivation of Soybeans and Cattle

In the case of soybean cultivation, over the last 60 years this crop has expanded from almost zero to more than 21 million cultivated ha. The cultivation of the soybean started in the more arid southern states of Brazil, but it has now extended to the center and western zones, invading mainly the Latin American savannah forest and to a lesser extent the tropical forest of the Amazon. One of the driving forces of the expansion of soybean agriculture has been the huge expansion of the cattle ranching in Brazil, mainly in the states of Mato Grosso, Pará, and Rondônia. The amount of cattle heads increased from 26 million in 1990 to 164 million in 2004. The International Finance Corporation (IFC), which is part of the World Bank, directly participated, for a short time, in the expansion of soybeans as well as in the cattle operation in Brazil.

Traditionally, the increase in cattle ranching has been identified as the leading cause of deforestation in the Amazon, but now soybean cultivation occupies a close second place. Currently, both factors together have caused the clearing of 80 million ha in Brazil (approximately equivalent to 10 percent of the country's total surface area), and since Brazil possesses a larger area of tropical forest, it also undergoes larger deforestation. Until the end of the 1970s, deforestation in Brazil was considered a minor problem that had a limited local impact. However, the situation has changed in a radical way. During the following 20 years, 50 million ha of forests were destroyed in the states of Pará, Amazon, Mato Grosso, and Acre, which constituted 14 percent of the Brazilian Amazon (CEPAL, 2000).

Many people have reiterated the danger that soybean expansion has on the ecosystem of the humid tropical forest. It has been estimated that in 2020, soybean production could destroy nearly 22 million ha of forests and savannas in Latin America.
Consequences of Deforestation

They are numerous factors that contribute to the uncontrolled deforestation of Brazil. The most notorious agents are the cattle farmers, who make good use of the subsidies granted by the government destined to stimulate the expansion of the livestock industry. The exploitations of gold mines, the flooding due to hydroelectric dams, and commercial tree harvesting are other important factors.

The long-term impact of deforestation on soil resources can be serious. The clearing of native vegetation cover for agriculture and subsequent burning exposes the land to the intensity of the tropical sun and to torrential rains. This can negatively affect the soil by increasing soil compaction, reducing organic material, leaching the few soil nutrients that exist, increasing aluminum toxicity, and thereby marginalizing agriculture. Subsequent cultivations, frequent tilling, and excessive use for cattle grazing pasture accelerates soil degradation.

Current Situation of Soil Degradation in Colombia

On the basis of a study (IDEAM, 2000) on soil degradation and land erosion for the decade of the 1990s, large soil removal and sedimentation in Colombia can be estimated as follows: 48 percent of the Colombian territory displayed some grade of degradation, of which 14.2 percent was very high degradation; 10.8 percent was high degradation; 8.9 percent was moderate degradation, 9.5 percent was low degradation, and 4.6 percent was very low degradation (Figure 5).

Figure 5. Represents the percentage distribution of the intensity of degradation of soils and lands in Colombia for erosion, removal in mass, and/or sedimentation.
According to the report, soil degradation processes present in Colombia include erosion, compaction, leaching of nutrients, pollution, salinization, and sodification (sodium-affected soils). This soil degradation results from activities such as deforestation, mining, intensive and extensive cattle raising, unsustainable agricultural systems, inappropriate use of water resources, indiscriminate burnings, and illicit coca cultivations.

**Deforestation and Land-use in Colombia**

In the watershed of the Q. Yepes River in the Sierra Nevada of Santa Marta, Colombia, the deforestation of the tropical humid forest from pre-Columbian times, the frequent use of fire and intensive grazing have caused severe erosion and reduction in fertility, which has led to the conversion of humid forest to savannas. Soil profiles indicate that erosion has moved approximately 50 cm of the soil in areas that are currently covered by pasturelands.

Due to increasing food demand, Colombia has chosen to incorporate new lands to increase production. The humid tropical regions have suffered the impact of an agricultural exploitation, which use inherited practices such as cutting and burning trees (Olmos and Montenegro, 1987).

**Current Status of Soil Degradation in Ecuador**

The system of resource utilization in Ecuador is a classical example of developing countries that are forced to intensively exploit natural resources, which can result in the creation of serious problems. The principal cause of loss of biodiversity in Ecuador is the destruction of natural forests. The rate of deforestation in the country is 2.3 percent per year and by extrapolating, this implies that the country would be totally deforested in the year 2025.

More than 60 percent of the paramo zone in Ecuador is classified as a zone of human intervention, and the large majority of it is being used for agricultural intentions. Because of this, several sectors of Ecuadorian society are concerned about the degradation of the natural resources in this zone caused by agricultural uses. The agricultural production systems have their foundations in the biophysical, technological, economic, political, and cultural surroundings.

Changes in these systems can be explained by the combination of causes such as integration to the market, access to new lands, access to technologies that increase land productivity, population pressure, and degradation of natural resources used by agriculture.

**Current Status of Soil Degradation in Ecuador**

Soil degradation is considered among the more serious environmental problems of Ecuador (Byers 1990; White and Maldonado, 1991). A study done by De Noni and Trujillo (1986), demonstrated that 12 percent of the soils in the country (31,500 km²) were exposed to active erosion.
Multiple forces have contributed to soil degradation of the region, including agricultural activity, monoculture crop production, high use of agrochemicals, and the cultivation and mechanical movement of the soil. Although the intense rains that fall on exposed soils commonly cause erosion, the high organic-matter content of black Andean soils facilitates a large degree of infiltration. As a result, runoff only occurs during the more severe rain events, that is to say, one or two times per year (De Noni and Trujillo, 1986; Harden, 2001).

The use of tractors on relatively moderate slopes (25-35 degrees) has resulted in the transport of large quantities of soil downward (Kooistra and Meyles, 1997). In the Ecuadorian Andes, mechanized cultivation of slopes has increased dramatically in the last decades, even to the point that the use of tractors is the primary cause of physical erosion and soil degradation.

Over-grazing on lands where cattle did not exist and the clearing of the forested parts of the slopes favor the acceleration of erosion and soil degradation in arid, semiarid, and sub-humid zones. These are caused by diverse factors at the intersection of climate and human activities. The problem of the deforestation, which allows water to run too quickly over uncovered slopes and wash away a large part of the humus, is the serious upsetting of the water balance.

**Current Status of Soil Degradation in Paraguay**

The economic base of the country is agriculture, especially the production of cotton and soybean for export. The agricultural sector generates 26.7 percent of the gross national product (PIB), employs 35.8 percent of the working population, and produces 90 percent of the registered exports (Kohler, 1992). Of these exports, about one half is exported without any processing.

**Factors that Lead to Soil Deterioration**

According to Kohler (1992), there are three key factors that lead to the deterioration of soils in Paraguay:

- Establishment of unsuitable regions for agriculture and/or cattle ranching;
- Application of technologies unsuitable for managing natural resources; and
- Rapid changes in macroeconomics.

The pressure for land strongly emerged after 1989 due to many occupations of forested territories on the part of the farmers. The first stage in the procedure for settling land was the request to the National Parliament for the expropriation of the land, which was and still is a useful means of enabling small farmers to have access to the land. The expropriation was facilitated by the land being regarded as “uncultivated” and “unused” by the owners. To counter this trend, from 1989 the landowners began a process of massive deforestation and delimitation of all estates regarded as unproductive, so that they would be classed as being “rationally managed” and therefore not subject to expropriation. This situation doubled average annual deforestation in less than a year, reaching a record level where less than 10 percent of the country’s total land is still wooded, and the remaining subtropical woodland is forecast to disappear in 2010 (Kohler, 1992).
The various aspects that affect the erosion process in agricultural areas include:

- The system of dividing properties to be distributed to the people is done without suitable planning of existent natural resources;
- Lack of adequate technical support to the producers in their re-adaptation in the new qualified areas;
- Most of the agricultural production is oriented to the demand of international markets, such as annual crops (soybean, cotton) that leave soils exposed to degradation;
- Intensification of agricultural mechanization in certain regions of the country that causes changes in physical soil characteristics such as compaction, less infiltration of rainwater and less retention of available water for plants;
- Insufficient local scientific information on the handling, conservation, and recuperation of soils;
- Lack of political will and budget allocation directed to the treatment of the problem of soil degradation; and
- To incorporate soil conservation into technical measures and credit assistance, and to minimize the time of assimilation of the technical conservationists.

Current Status of Soil Degradation in Peru

Soil Degradation

Soil degradation is also linked to human intervention owing to demographic pressure and improper land use. Erosion is most obvious in the mountain region. At a national level, erosion covers an area of some 60 million ha, or 55 percent of the area of the territory. Also, there is a fragile equilibrium in regards to erosion in the lowland jungle areas. Therefore, destroying the plant cover accelerates the erosion process in the hilly formations, which is typical of 70 percent of the physiographic scenario of the lower Amazon jungle. Erosion occurs on hillside soils without plant cover and is subject to heavy rainfall. However, this process is partly rooted in social and economic aspects.

The Cultivation of the Coca Leaf in Peru

The cultivators of coca in the Andean Region prefer to locate their cultivations in remote forest zones, almost always in mountainous and steep terrain. The sparse ground-level vegetal layer and difficult access to these zones generally stimulates the production of illicit cultivations. In order to prepare the land for illicit cultivations, forests are devastated and burned before sowing the coca. Due to the low fertility and the need to evade the authorities, the fields are abandoned after two or three plantings and the new fields are opened inside the jungle. This practice accelerates the deforestation of large extensions of forests and destroys lumber resources that would be available from a more sustainable use of the forested land. Additionally, the recurrent practice to sow in such a fragile soil can rapidly lead to environmental deterioration and the depletion of natural resources, especially in the loss of the topsoil layer and sedimentation downstream.
In 2000, the deforestation affected 9.6 million ha (12.6 percent of the Amazonian forest of the country), and can be calculated on an average of 261 thousand ha deforested per year (0.35 percent/year). About 73 percent of these areas are in different stages of forest formation, known as secondary forests, and the product of various degradation actions (slash and burn agriculture, erosion, etc. [ENDF, 2001].

Current Status of Soil Degradation in Uruguay

The Eastern Republic of Uruguay is located in the temperate region of southeastern South America. Uruguay is an essentially agricultural country with cattle-ranching and agriculture constituting over 85 percent of the country’s exports. The industry continues to transform primary raw materials into the agricultural sector.

Soil Degradation

In Uruguay, it is considered that soil degradation constitutes a complex process whose advance is manifest reduction of soil productivity and the associated ecosystems. These successive reductions in productivity correspond to different processes in the country, mainly water erosion, as well as to the socioeconomic, institutional, legal, political, and cultural factors.

In the same way, erosion represents a problem that also generates direct costs for the country, like the need to continuously replace lost nutrients, or the depreciation of land in the more affected zones.

A study by Beloqui and Kaplán (1998) concluded that although 30 percent of the land displays some degree of degradation, the deterioration of the soil properties is relatively low in relation to its prolonged use; nevertheless, the degradation of the structure of the surface horizons is closely related to the loss of organic matter.

Current Status of Soil Degradation in Venezuela

Soil Degradation

In Venezuela, like the other tropical countries, the more common problems of degradation are water erosion, sealing, compaction, salinization, and sodification Pla (1988). According to the same author, also present are processes of physical and chemical degradation accompanied by biological degradation. Most of the degradation problems not only depend on the intrinsic soil characteristics, but also on the very aggressive climate in the majority of areas and of the adoption of agricultural production systems and practices taken directly from other parts of the world with different climatic and socioeconomic conditions (Pla, 1988).

According to FAO, deforestation in Venezuela is principally due to the demand for lands for agricultural purposes, but it is also related to the limitations of the political system for the establishment and consolidation of effective agrarian reform (FAO, 2000).
During the period from 1990 to 2000, Venezuelan forests were cut at a rate of 500,000 ha per year to be converted into agricultural land and pastureland for cattle. It is precisely in the Guarico and Apure plains where over-grazing is common, because the natural pastureland is not able to maintain the existing number of animals. If the present-day rate of deforestation in these two states is constantly maintained, it is anticipated that an almost total disappearance of the forest will occur by 2020.

In spite of the significant advances in national legislation in environmental matters and a considerable increase of the areas protected in recent years, the budgetary and personnel limitations in public agencies and the application of legal requirements are still very weak. Also the clearing of land continues at a high rate (according to estimates, the highest in the region), which results in increasing social pressure and the unjust system of tenancy of effective land-use in the country (Ministerio del Ambiente y de los Recursos Naturales, 2000).

Agriculture and livestock are the main causes of this large-scale deforestation. The process of felling trees and the burning of the remaining vegetation for pasturelands, which later will be converted into corn and soybeans fields, along with the gradual deterioration of soils and water reserves, have caused the destruction of the majority of humid forests, dry forests, and the fertile soils suitable for the agricultural production. It is estimated that south of Lake Maracaibo, 95 percent of the forested areas have disappeared to establish low efficiency cattle-ranching. However, this activity produces 70 percent of the milk and half of the meat consumed in the country.

The problems of land degradation in Venezuela worsens every day, due principally to the rapid expansion of crops that utilize a great diversity of production methods and technologies that are unsuitable for the various soil types, climate, and socioeconomic conditions. These factors are aggravated by the increasing demand for highly fertile agricultural land for urban and industrial uses. This situation has reduced agricultural production because it has become necessary to introduce agricultural raw materials and practices that guarantee yield, but that cause soil degradation.

Conclusions and Recommendations

Although there are differences in the available statistics on the various land uses in South America, the following general trends are in agreement:

1) Lands dedicated to arable crop land and pastureland with the associated strong decrease of the forest area have increased. A more detailed analysis reveals that an important trend has been the conversion of traditional cultigations like dry bean and corn to new export crops, in particular soybean and sorghum, and a clear relationship exists between deforestation and the increase of pasturelands for livestock.

2) It has been verified that erosion constitutes one of the most serious and generalized forms of land degradation in the region. This has increased during past decades by the uncontrolled expansion of cattle ranching in non-suitable zones and the extension of agriculture on slopes.
susceptible to erosion, which in certain countries has forced extensive areas of land to be abandoned.

3) The principal problems of soil degradation that affect the region of southern America include: water erosion, wind erosion, advancement of dunes, extraction of soil, salinization, drainage problems, loss of fertility, acidification, soil compaction, loss of soil structure, biological degradation, desiccation of fertile plains and valleys, landslides, and irreversible changes in soil use and pollution.

4) Since the time of the Spanish conquest, Chile has been a country with serious problems of soil erosion, which has been particularly studied in the coastal Mountain Range. Chile has undergone erosion problems caused by the conversion of areas to cattle ranching, extraction of firewood for fuels, indiscriminate use of fires, and the conversion of land to cereal and horticultural use.

5) The impacts that cause soil modifications by anthropogenic intervention have been magnified with increasing mechanization, agrochemicals application, in particular by synthetic fertilizers, pesticides, herbicides and fungicides, as well as the use of improved high-yielding crop varieties, increased irrigation, etc.

6) One of the most important environmental problems of the region is associated with the expansion of the cattle economy and the resulting conversion of soils from traditional cultivations to the production of cattle feed (soybean and sorghum) and the conversion of forest areas to pasturelands.

The following are several erosion control strategies that can be considered:

- Increased vegetation cover to reduce the impact of energy from raindrops on the soil surface;
- Increased water infiltration in the soil profile by reducing surface runoff and to increase soil water availability for crops;
- Control surface runoff to reduce the erosive potential of flowing water;
- In addition to the local community, national governments must cooperate in remedying soil damages caused by human activity (erosion, chemical pollution, and others);
- Landowners must carry out productive activities based on the capabilities and ecological potentialities of the soil, preserving soil quality, and in maintaining the use of fertile soil for agricultural activities;
- To apply the following agroecological techniques: direct sowing, minimum tillage, crop rotation, cover crops, controlling cattle grazing, fertilization, composting, earthworm humus, organic fertilizers, and other appropriate technologies;
- To eradicate burning and fires and to practice regulated cutting;
- To manage areas based on agroecological capacity and soil potential;
- To regulate crops and soil techniques on high sloping land; and
- To define planning policies for rural areas, to regulate and manage appropriate land use policies, and to determine the minimum area for changing land use.

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Review of Case Studies on Successful Measures to Manage Land Use, Protect Land, and Mitigate Land Degradation

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Abstract

Land degradation is a major concern on matters relating to sustainable agricultural development and long-term food productivity in Africa. Notwithstanding other factors, land degradation in most African countries has been driven by disparities in land distribution. This has led to a concentration of people on limited portions of land and the need to address their development needs and issues of food security. The degradation of soil has been further exacerbated by the subsequent increase in population on marginal lands. Agriculture continues to play an important role in sustaining the livelihoods of most African communities. It is often affected by climatic variations, which contributes to land degradation. Some efforts have been undertaken to reverse the process of land degradation and to promote sustainable land practices. These efforts vary at different communities depending on the nature and cause of degradation. It is a joint effort of governments, communities, research institutions, academia and non-governmental organizations. This paper reviews case studies on successful measures to manage land use, protect land, and mitigate land degradation in selected African countries.

Introduction

Land degradation occurs mostly because of land management practices or human development that is not sustainable over a period of time. Long-term food productivity is threatened by soil degradation, which is severe enough to reduce yields on approximately 16 percent of agricultural land, especially croplands and pastures in Africa. About 46 percent of the African continent is threatened by the processes of land degradation (World Meteorological Organization [WMO], 2005). Many countries in Africa experience severe climatic perturbations, resulting in droughts of varying intensities, which are often characterized by severe spatial and temporal fluctuations in rainfall with high variability. This affects issues relating to food security, crop production, and general agricultural economics. Land degradation is partly a result of the interrelationship between an increase in population and a decline in agricultural productivity.

Several projects have been undertaken at varying scales in Africa to address the problem of land degradation in a quest for sustainable agricultural development. These projects range from capacity building, farmer-extension participatory approach and researcher managed trials, promotion of sustainable land management practices, and the use of climate information and geo-information technology in informing sustainable agricultural development. This paper
provides a review of successful case studies to manage land use, protect land, and mitigate land degradation focusing on South Africa, Namibia, Morocco, and Uganda.

South African Case Studies

Measures to Protect Land, Manage Land Use and Mitigate Land Degradation

Sustained agricultural production and sustainable rural livelihoods are underpinned by an ecosystems approach comprising the integrated management of the land, water, and biological resources. In South Africa, with diversity in both natural resources and management, best practice technologies per ecosystem are at the core of sustainability. Implementation of sustainable agricultural development projects is in line with several international agreements including the World Summit on Sustainable Development (WSSD).

LandCare Programme and Water Harvesting Techniques

The Natural Resource Management Programme is largely encompassed in the country’s LandCare Programme initiated in 1989 and the consequent LandCare Policy. The LandCare Programme is a community-based and government-supported programme to promote sustainable land management practices and to stop and reverse land degradation. More than 300 rural development projects have been implemented and these multidisciplinary projects follow an integrated ecosystems approach. The success of LandCare projects are attributed to the adoption of best management technologies utilized in on-site experimentation and demonstrations. South Africa’s LandCare programme was designed in recognition that land degradation and water shortages are serious environmental threats, affecting each and every person through the economy, the environment, and poverty.

Small-scale and homestead crop production are often practiced in areas marginal for crop production as a result of low, erratic, and unevenly distributed rainfall and soils with a low-rainfall use efficiency. This triggered research on the development of water harvesting technologies based on the ecotope concept, describing the quantitative soil water regimes of benchmark crop ecotopes. An ecotype is defined as the smallest ecologically distinct geographic feature in a land use classification system. Water harvesting technology projects, similar to LandCare projects, are based on on-site demonstrations to facilitate adoption. The in-field rainwater harvesting technique was designed to capitalize on limiting soil characteristics such as low water infiltration rate and crusting; to optimize selected soil characteristics such as high water storage capacity and high fertility status; to maximize rainfall use efficiency; and to bridge the dependency of small-scale and homestead farmers on mechanized agriculture (Morgenthal, et al., 2005a).

ARC - Sustainable Rural Livelihoods Programme

The purpose of the Agricultural Research Council (ARC) – Sustainable Rural Livelihoods Programme is to promote sustainable agricultural development, improve the quality of marginalized groups and rural communities, in order to alleviate poverty through enhanced production, creation of employment opportunities, and a more equitable distribution of resources. The programme provides technical support to ensure successful farmer settlement, enhance
agricultural productivity of the Resource Poor Agriculture sector in rural areas through the development of integrated farming systems and value-added skills development amongst related rural households. The programme also promotes natural resource management strategies for Resource Poor Agriculture (Small Scale Farmers) for addressing problems arising from the interaction between agriculture and the environment, with priority reference to communal areas.

Working for Wetlands Programme

The departments of Environmental Affairs and Tourism, Water Affairs and Forestry, and Agriculture, together with partners in provincial and local government and civil society, especially the Mondi Wetlands Project, have jointly launched the Working for Wetlands programme. The programme addresses the protection, rehabilitation, and sustainable use of wetlands. The programme also addresses commitments under several international agreements, especially the Ramsar Convention on Wetlands.

Working for Wetlands rehabilitation projects are intended to produce sustainable environmental outcomes, using implementation models that simultaneously contribute to the employment creation and skills transfer objectives of government’s Expanded Public Works Programme. Funding for these activities is provided by the Department of Environmental Affairs and Tourism to the South African National Biodiversity Institute (SANBI), which hosts the programme. All rehabilitation interventions are undertaken within the context of improving the integrity and functioning of the ecosystem, and include measures that address both causes and effects of degradation. A guiding principle is to raise awareness and influence behaviour and practices impacting on wetlands, rather than focusing exclusively on engineering solutions.

South Africa’s Involvement in International Initiatives for Mitigating Land Degradation

World Overview of Conservation Approaches and Technologies (WOCAT)

South Africa, under the auspices of the Department of Agriculture, participates in WOCAT. WOCAT was launched in 1992 and was accepted, in 1996, as a global programme by the International Soil Conservation Organisation. WOCAT uses a standardized framework for the evaluation of soil and water conservation. Data is collected by means of questionnaires. The South African WOCAT database is maintained by Agricultural Research Council – Institute for Soil, Climate, and Water (ARC-ISCW), South Africa’s project leader. The objective of WOCAT is to contribute to the sustainable use of soil and water through the collection, analysis, and presentation of world-wide soil and water conservation technologies/approaches and to promote improved decision making and land management. The system enables an evaluation of the strengths and weaknesses of any particular technology under given circumstances on the basis of a set of indicators. Such an assessment may be made of a technology in its present environment or may be used to assess its applicability in another area. By 2003, the WOCAT database contained some 300 technologies and 120 approaches from more than 35 countries. Sub-Saharan African countries account for two-thirds of these, with more than 75 technologies related to water harvesting and soil water conservation. The WOCAT database is accessible at www.wocat.net.
**Food and Agriculture Organization (FAO) of the United Nations Land Degradation in Dryland Assessment (LADA)**

South Africa is one of six pilot countries to participate in the global LADA project. The LADA project will upscale and contribute to the objectives of United Nations Conventions such as the Convention on Biological Diversity (CBD), Convention for Combating Desertification (UNCCD), and Framework Convention on Climate Change (UNFCCC); and global initiatives such as Agenda 21 supported by World Summit on Sustainable Development. LADA is aimed at reviewing and synthesizing data and information of relevance to the development and assessment of drylands and at developing, testing and revising integrated land degradation assessment approaches and methods. The Soil and Terrain Digital Database (SOTER) developed and maintained for South Africa by ARC-ISCW, will form an important component of LADA.

**Applications of Geo-information and Remote Sensing in Natural Resource Monitoring**

**Coarse Resolution Satellite Imagery Database**

The Agricultural Research Council – Institute for Soil, Climate and Water (ARC-ISCW) houses a fully processed 1-kilometer spatial resolution National Oceanic and Atmospheric Administration – Advanced Very High Resolution Radiometer (NOAA-AVHRR) dataset spanning 18 years (from 1985 to 2004). The database consists of daily raw channels (5 bands) and angle images, Normalized Difference Vegetation Index (NDVI), Land Surface Temperature (LST), and Active Fire data. Initiatives are also undergoing to extend the ARC-ISCW’s database through alternative sources of course resolution data from Spot-4 VEGETATION and processed data from the Moderate Resolution Imaging Spectroradiometer (MODIS). The SPOT VEGETATION satellite data stretch from 1998 to date and the MODIS data from 2000 to date. The MODIS data is obtained from the Land Processes Distributed Active Archive Center (LP DAAC), located at the U.S. Geological Survey's EROS Data Center http://LPDAAC.usgs.gov and SPOT VEGETATION is provided with courtesy of the VEGETATION Programme and the VGT4AFRICA project, produced by Flemish Institute of Technology (VITO).

The institute also hosts an Agrometeorology Databank, which archives South Africa’s climate data, ranging from 1900 to date. The data is used for various applications in assessment and monitoring of natural resources.

Figure 1 demonstrates the use of long-term climate data (rainfall) in calibrating and validating satellite derived observations for natural resource monitoring. Shifts in the 500 mm isohyet were complemented by shifts in the cumulative NDVI. The line graph for rainfall indicated a strong cyclic activity in the experimental region. The long-term trend graph confirms high variability in the study region. Both the NDVI and rainfall maps indicated areas with high variability in the central parts of South Africa.
Early Warning Project on Drought and Its Impact on Food Production

The ARC - ISCW developed an early warning and decision support system for food security, funded by the South African Department of Agriculture. The system is referred to as *Umlindi* (meaning the watchman) and provides information to decision makers on the current drought condition, fire risk, and vegetation conditions based on the interpreted satellite data and climate data. The *Umlindi* system proved to be useful in predicting the production of maize crops against the predicted extent of drought (Petja, 2002). The information is provided to the National Crop Estimates Committee and the National Agrometeorological Committee (South Africa) in the form of monthly reports/advisories, newsletters and the Website (www.agis.agric.za/).

Previously NDVI data calculated from NOAA (AVHRR) data was used to monitor drought occurrences but during the past 3 years SPOT VEGETATION is increasingly being used to monitor and predict drought conditions. Results obtained include trend analyses from long-term datasets, cumulative and maximum composites over a growing season, and difference maps between different periods to flag drought occurrences.

National Vegetation Cover and Grazing Capacity

To ensure sustainable use of natural resources and to prevent degradation and desertification of rangelands, the Conservation of Agricultural Resource Act (Act 43 of 1983) was promulgated. The act requires the implementation of a grazing capacity map to give guidance to farmers on the
Namibian Case Study

Land Degradation at the Uukwalaudhi Community

Imbamba (2002) undertook an extensive study of land degradation in Northern Namibia. He focused on the major causes of degradation and mitigation strategies. Like in most of the former colonies, land in Namibia was inequitably distributed according to race. The White people owned freehold title to 60 percent of agricultural land, which they could sell and purchase or borrow money on from lending institutions, using it as collateral. About 40 percent (about 33.4 million hectares) of the land held by the Blacks could not be sold or purchased freely because it belonged to the community. The land held by the Blacks (homelands and reserves) was located in areas with poor climatic and soil conditions as well as inadequate water resources.

Uukwalaudhi is situated in the Ovambo region, northern Namibia and constitutes approximately 44 percent of the national population. The population of the Uukwalaudhi community was 34,448 in 1990, and the population growth rate was estimated to be 3.8 - 4.2 percent.

The Uukwalaudhi community is composed of semi-sedentarized farmers who raise some crops but move their livestock about in search of fodder and water. The Ovambo region is semi-arid with variable rainfall, which decreases from about 500-mm per annum in the east to about 300-mm in the west. The Uukwalaudhi region, which stretches from the Cuvellai flood plains to Kunene, experiences great variability in rainfall as well as the east-west rainfall gradient. The rainy season extends from October to April with the highest amount falling between December and March. Because of the high average evaporation rates, it is estimated that a considerable amount of rainfall (80 percent) evaporates shortly after precipitation.

In common with other former tribal homelands in Namibia, the environmental and socioeconomic impacts of land degradation in Ovamboland are distinctly striking because most of the inhabitants depend on land resources for their survival. Owing to the high degree of dependence on natural resources for human needs, the majority of the Uukwalaudhi people have become highly vulnerable to environmental changes, particularly those related to the depletion of land resources. Like many other rural communities, the Uukwalaudhi people are insecure and vulnerable to environmental related diseases, food insecurity, economic losses, and civil strife.

Causes of Land Degradation and Mitigation Strategies

According to Imbamba (2002), land degradation in the Ovambo region has been on the increase due to a variety of factors such as climatic variability, drought, soil erosion,
overstocking/overgrazing, deforestation, and woodland degradation. The intensification of the above environmental changes has, in turn, impacted negatively on the livelihoods of the local Uukwaluudhi community, resulting in a decline in agricultural production, scarcity of fuel wood, the disintegration of common property management, and increased food insecurity, as well as a decline in the quality of life. In addition, the changes in the environment have deepened poverty as well as contributed to the migration of the local communities to marginal areas. Local and national initiatives have been put in place to halt and reverse the environmental changes. In order to accelerate land conservation in Ovamboland, local communities (especially women) began to be empowered to participate fully in making and implementing decisions on the sustainable management of land resources.

In Namibia, one of the mitigation strategies has been the development of land policies in order to address equitable land distribution and sustainable land management. Community participation in forest management and land tenure reforms has been promoted and has gained momentum. Forest management authorities have also been established.

Namibia became the first African country to formulate a National Action Programme to combat desertification (NAPCOD). The country ratified the UNCCD on May 16, 1997. The objective of Namibia’s Programme was “to combat the processes of desertification by promoting the sustainable and equitable use of natural resources suited to Namibia’s variable environment for the benefit of all citizens both present and future.” The programme addressed the political, socio-economic as well as biophysical aspects related to land degradation.

**Morocco Case Study**

**Livestock-Based Livelihood Systems and Associated Environmental Changes**

Most communities in the eastern Region of Morocco depend largely on livestock for sustenance of livelihoods. However, their activities are often affected and limited by environmental conditions. Salem (2002) reported on livestock based- livelihood systems in Morocco and their coping strategies that promote environmental protection. The communities in this area originally adopted a tribal structure to govern access to and control over natural resources. Each tribe had its well-established territorial boundaries that were respected by others. Access was limited to such boundaries by clans of the same tribe. Ancestral rights to rangeland use were an integral part of the traditional institutions that governed access to grazing grounds. Each tribe had its chief, who sat on the local council made of chiefs of all the tribes. Strict rules existed with respect to timing, zoning, and duration of grazing. These rules governed the complex user rights to pasture shared by a number of families and many generations.

Seasonal migration patterns of the population followed the ecological features and the climatic changes of the area. The northern high plateau (Dahara) in the Oujda province is less arid than the southern pre-Saharan environment (Sahara) in the Figuig province. The two landscapes are separated by a small mountain chain rising to 1,800 meters. The amount of rainfall decreases from 450 mm in the Dahara to 150 mm in the Sahara. Vegetation cover varies between the two regions accordingly. In the Dahara, perennial grass and woody shrubs grow with abundance. In the Sahara, a greater diversity of shrubs and succulents replace perennial grasses. In low-lying
landscapes, land maintains soil moisture and provides a hospitable environment for medicinal herbs, wild mushrooms, and large ground truffles.

For centuries until the late 1960s, inhabitants of the eastern Region maintained a nomadic lifestyle. During wintertime, tribes of the Dahara area moved their herds to lower elevations and the warmer climate in the Sahara. Along the way, men herded their sheep and goats to shrubs and grass. Women collected medicinal herbs, fuel wood, mushrooms, and truffles to trade in the local market or souk. Reverse migration from the Sahara to the Dahara would take place during spring. Herders used to carry their tents on camels and herd their sheep and goats over distances of about 250 kilometers (km) to take advantage of available resources in their two ecologically diverse zones. However, Salem (2002) further reports that most of the communities have permanently settled over the last 4 decades.

Coping Strategies

The 1980s witnessed consecutive years of drought, which exacerbated land degradation due to overgrazing. Rangeland degradation also adversely affected the health status of livestock. Given that livestock raising was the principal source of income for the population, their economic vulnerability became more pronounced through the poor nutritional status of the animals, and caused loss of subsistence and income, especially in the dry season. The small herders had extremely limited mobility and could not afford to move their herds by trucks to less degraded grazing grounds. They were obliged to herd their flocks near the water points that were often overgrazed.

A project was designed and implemented to reduce vulnerability of the local communities in the eastern Region (Salem, 2002). The project utilized a mixture of old and new institutions to establish an operational common property management (CPM) regime as a way of reversing environmental degradation and reducing human vulnerability. The project’s overall objective was to raise the income and living conditions of some 9,000 families, while improving and sustaining productivity of some 750,000 hectares (ha) of grazing land. A related objective was the formation of “ethnolineal” cooperatives based on traditional tribal structures and territorial boundaries. These more representative and diverse cooperatives of herders were established to help organize them into groups to facilitate recognition of and compliance with the designed regime of CPM. The project intervened in six areas: i) pasture improvement; ii) livestock development (animal health, genetic improvement); iii) extension, training, research, iv) credit for small herders, v) women’s activities, and vi) institutional strengthening. Total project cost was $45.22 million (U.S.), of which $14 million was a loan from IFAD, $6.43 million from the African Development Bank, $18.22 million from the African Development Fund, and $6.57 million from the government of Morocco (IFAD, 2000, cited by Salem, 2002).

Uganda

Land Degradation in Uganda

A pilot study by Olson and Berry (2003) was undertaken in Uganda to examine the extent and impact of land degradation. They found that a large percentage of land in Uganda is arable with
much of the land not yet under cultivation. Approximately 75 percent of the country’s land is relatively fertile and receives sufficient rainfall for rainfed cropping and pasture. Only around 30 percent of the arable land is currently under cultivation. The agricultural population is relatively concentrated in eastern, southern and western Uganda; and zones within those areas have high population densities. In several regions, important signs of soil degradation trends are apparent including decline in yields and a switch to crops that demand fewer nutrients. Food production has not kept up with the country’s population growth increase despite an expansion of area under crops. According to Olson and Berry (2003), per capita food production hit a low in 1980, and even with recent increases, it has not reached the levels of the 1970s.

The expansion of area under cultivation has been primarily due to short- and medium-distance migration and conversion of wetlands, grasslands, and forests to crops. These came along with some environmental problems. It is critical to reduce the trend of land degradation in areas already under cultivation, and to ensure sustainable land management practices in order to prevent degradation in the areas that will be placed under cultivation in the near future. Uganda’s comparative advantage in climate and soils means that it has the potential to become an important producer of agricultural products if sustainable systems of production are implemented.

**Mitigation Strategies**

Olson and Berry (2003) identified regional and international institutions in Uganda having interest in mitigating land degradation. The mitigation emphasizes that the most promising and profitable technological option for improving soil productivity is through using a combination of organic and inorganic fertilizers, with erosion control measures where necessary. Sources for organic materials include manure, coffee husks, and other crop residues. Improved management of existing organic sources, such as methods integrating manure and composting, may significantly increase soil organic matter and reduce nutrient loss. Other sources of organic materials include legume cover crops, useful especially where population densities are intermediate and fallow is still practiced. They can also produce high-quality fodder as well as green manure and other soil enhancing properties. A rotation with *mucuna* (velvet bean) earned higher returns than with fertilizer for some areas in eastern Uganda. In addition, ground cover has been found to be critical to reduce erosion and fertility losses associated with erosion.

The soils of Uganda are generally deficient in phosphorus, and increasing this mineral through biomass transfer or applying rock phosphate improves productivity. Some biomass, such as *Tithonia (T.) diversifolia*, has been found to be of very high quality, and it increases phosphorus and soil productivity after being transferred directly onto fields or incorporated into compost. Combining *T. diversifolia* with rock phosphate has produced the highest yields, though *T. diversifolia* use alone was most profitable. Phosphorus rock is available in Tororo near Sukulu rock and Mbale near Busumbu rock. Use of the rock in nearby areas, especially when combined with nitrogen-fixating legumes, has also shown promising results.

Analyses of the costs and benefits of various technologies to farmers, especially in land- or labor-constrained regions, are important for technology development. In eastern Uganda, it was found that investment in some technologies was only profitable after the soil had been depleted
of nutrients, but that for maize they were profitable only in areas of higher rainfall and better soils. Farmers in areas where *T. diversifolia* was tested then adapted to their own technology requirements, the higher labor costs, in particular, would probably need to be met by returns from high-value crops. As market integration improves, the economics of investing in these technologies is constantly changing. Improving the farmer-researcher-extension linkages through participatory research is critical. The variability between farmers and households that affect resource constraints and influence adoption of technologies, including wealth and gender, also need to be considered.

Semi-arid areas have received much less attention by researchers and have additional research needs including water harvesting, storage and use methods, and improved integration of crop and livestock production. The processing and marketing of commodities produced in semi-arid areas, and infrastructure development, would also benefit from additional research.

**Conclusion**

This review of activities aimed at protecting land, managing land use, and mitigating land degradation shows that most African countries are committed to addressing the threats caused by environmental degradation to the agricultural sector and food security. The commitment is jointly shared by both the national, provincial, and local governments; together with the research institutions, parastatals, non-governmental organizations, and universities. The mitigation strategies promoted at countries aims at ensuring long-term sustainability of agricultural development. There should be a coordinated effort to share experiences learned from successful case studies with most of the African countries and the rest of the world.

**Acknowledgements**

The author acknowledges projects undertaken at Agricultural Research Council (South Africa) from which most of the information was sourced. These include the ARC – Sustainable Rural Livelihoods projects, LandCare Projects, Coarse Resolution Satellite Imagery Project, National Grazing Capacity Project, LADA, WOCAT, and also the Working for Wetlands Programme, which is coordinated by the South African Biodiversity Institute. A majority of projects aimed at mitigating land degradation in South Africa are funded by the Department of Agriculture. The author also acknowledges information on projects in other countries sourced from the Africa Environment Outlook Initiative.

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Natural Disaster Reduction in Coastal Lowland Areas

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Abstract

In recent years, the impacts of natural disaster are more and more severe on coastal lowland areas. With the threats of climate change and sea level rise, the reduction of natural disasters in coastal lowland areas receives increased attention. Based on a number of literature sources, this paper summarizes the categories and characteristic of natural disasters emerging in coastal lowland areas, such as windstorm and storm surge, tropical cyclones and tropical cyclone winds, tsunamis and floods, and analyzes the most devastating natural disasters in coastal lowland throughout the world in 2005. This paper also summarizes the effects of typhoons on the coastal lowland areas of China in 2005 and analyzes the natural disaster mitigation measures and research results. Finally, the paper discusses the vulnerability assessment and response strategies for natural disasters.

Introduction

The World Meteorological Organization (WMO, 2006) estimates that about 90 percent of all natural disasters is caused by weather, climate, and water. Recently, Munich Reinsurance Company indicated that economic losses from natural catastrophes totaled over U.S. $160 billion in 2005 (Hoeppe, 2007). The Fourth Assessment report of the WMO/UNEP Intergovernmental Panel on Climate Change (Rosenzweig, et al., 2007) has documented climate-change induced effects in some 100 physical and 450 biological processes. In the Russian Arctic, higher temperatures are melting the permafrost, causing the foundations of five-story apartment buildings to slump. Worldwide, rain is often more intense. Floods and storms are more severe, and heat waves are becoming more extreme. Rivers freeze later in the winter and melt earlier. Trees flower earlier in spring, insects emerge faster, and birds lay eggs sooner. Glaciers are melting and there are indications that the global-mean sea level is rising. The rate of climate change expected over the next 100 years is unprecedented in human history. Sea level rise will increasingly affect coastal margins. But global warming will also alter several other drivers that will impact on coastal areas, such as sediment runoff from land, change in wind and wave patterns, altered ocean currents, warmer sea temperatures, and the expectancy of more intense storms. During the Intergovernmental Panel on Climate Change’s (IPCC) Third assessment, it published Planning for Climate Change Effects on Coastal Margins (Bell, et al., 2001).

There are many kinds of natural disasters that can affect coastal lowland areas. For example, numerous natural disasters that affect central Vietnam such as typhoons, river flooding, flash flooding, inundation, landslides, riverbank erosion, coastal erosion, drought, and all other adverse natural phenomena, are preventing sustainable development of the region and thus keeping its inhabitants mired in poverty (Food and Agriculture Organization (FAO, 2003). In New Zealand, many coastal zones and small islands experience natural hazards including storms,
strong winds and heavy rain, subsequent flooding, droughts, submarine geological hazards (under-water landslides and volcanoes), tsunami, sea level rise and climate change, coastal storm surge, extreme tides, hazardous waves, and the resulting coastal inundation and erosion (National Institute of Water & Atmospheric Research [NIWA, 2005a and 2005d]). Because of these hazards, systems are developed to monitor and predict these extreme events and while humans cannot control the environment, people and communities can mitigate the impact of hazards with preparation and warnings.

Natural Disaster in Coastal Lowland Areas

Windstorm and Storm Surge

Worldwide, windstorms (including storm surges) are responsible for a greater number of damaging events than any other type of natural disasters — approximately one-third of all losses owing to nature’s forces can be attributed to windstorms. Windstorm damage has been extremely severe in recent decades and it is evident that both the frequency and severity of windstorm disasters have increased (Berz, 2005). Munich Re (2003) indicated that windstorms clearly dominate the catalogue of the costliest natural disasters to the insurance industry. They noted that until 2003, of 37 disasters, which have caused insured losses of U.S. $1 billion and more, 29 were windstorm disasters, whereas only six stemmed from other types of atmospheric extremes and only two from earthquakes. The research on windstorms mainly includes: generation processes and behavior of severe weather systems, frequency and tracks of cyclones, extreme wind climates, and wind modeling.

According to Federal Emergency Management Agency (FEMA, 2006a), storm surge is defined simply as water that is pushed toward the shore by the force of the winds associated with the storm. This advancing surge of water combines with the normal tides to create the tropical cyclone storm tide, which can increase the mean water level several meters or more. Storm surge can cause severe flooding in coastal areas, particularly when the arrival of the storm coincides with local high tides. FEMA has noted that the greatest potential for tropical-cyclone related deaths is from the storm surge. Storm surges in the southern North Sea pose a complex, persistent, and perhaps growing threat to the surrounding coastline of northwest Europe (Heaps, 1983; Lamb, 1991).

Tropical Cyclones and Tropical Cyclone Winds

Tropical cyclones are products of the tropical ocean and atmosphere and are powered by heat from the sea. As tropical cyclones make landfall, they can produce storm surge along the coasts, high winds, tornadoes, and both torrential rains and flooding. Coastal communities deciding how strong to make their structures need to consider the strength of tropical cyclone winds and the pressure tropical cyclone winds generate. As winds increase in speed, the pressure against objects or a wall of a house increases with the square of wind speed so that a threefold increase in wind speed gives a nine-fold increase in pressure (ASCE, 2003). For example, a 40 kilometers per hour (kph) or 25 miles per hour (mph) wind causes about 1.6 pounds of pressure per square foot, and a 201 kph (125 mph) wind becomes 1,250 pounds. The American Society of Civil Engineers (ASCE) points out that for some structures, this force is enough to cause
failure. So far, tropical cyclone research has mainly focused on the mitigation of tropical cyclone damage to people, the economy, and the built and natural environments.

**Tsunamis**

Tsunamis are temporary oscillations or waves in the ocean which have periods longer than wind waves or sea swells, but shorter than ocean tides. A tsunami is usually created by a sudden movement or elevation change of the ocean floor from events such as earthquakes, underwater landslides, and underwater volcanic eruptions (NIWA, 2005b). According to the International Tsunami Information Centre (2006a), hosted by the Intergovernmental Oceanographic Commission (IOC) of United Nations Educational, Scientific and Cultural Organization (UNESCO) [http://ioc3.unesco.org/itic](http://ioc3.unesco.org/itic), the time between wave crests can range from 5 to 90 minutes, and the speed of the wave in the open ocean can average 724 kph or 450 mph. Tsunamis reaching heights of more than 30 meters (100 feet) have been recorded. As the waves approach the shallow coastal waters, they appear normal and the speed decreases. Then as the tsunami nears the coastline, it may grow to great height and crash onto the shore, causing much destruction. Tsunamis occur a few times a year, but generally go unnoticed. Larger tsunami can cause coastal flooding, erosion, damage to buildings, and loss of life in extreme cases.

If a tsunami has been generated, there is no way of estimating the size of the wave. Pacific-wide warnings can generate many hours in advance via the Pacific Tsunami Warning Center in Hawaii run by the U.S. National Oceanic and Atmospheric Administration (NOAA) [http://www.prh.noaa.gov/ptwc](http://www.prh.noaa.gov/ptwc). There is also the West Coast/Alaska Tsunami Warning Center ([http://wcatwc.arh.noaa.gov/](http://wcatwc.arh.noaa.gov/)), which is responsible for tsunami warnings for the United States in California, Oregon, Washington, Alaska; and the Canadian Province of British Columbia. NOAA provides an online tsunami database at [http://www.ngdc.noaa.gov/hazard/tsu.shtml](http://www.ngdc.noaa.gov/hazard/tsu.shtml). Tsunami is a disaster that is devastating to the natural and man-made environment. Most deaths during a tsunami are a result of drowning and other hazards include flooding, polluted water supplies, and damaged gas lines (FEMA, 2007).

About half-a-dozen times per century, a tsunami sweeps across the entire Pacific, and sets the entire ocean in motion for days according to the International Tsunami Information Center (ITIC) [ITIC, 2006b]). For example, the 1960 Chilean tsunami caused death and destruction throughout the Pacific with Hawaii, Samoa, and Easter Island all recording waves exceeding 4 miles. From this tsunami, 61 people were killed in Hawaii and 200 in Japan. The ITIC stated that a similar tsunami in 1868 from northern Chile caused extensive damage in the Southern Pacific Islands, Hawaii, Samoa, and New Zealand. Also destructive tsunamis have been generated in the Atlantic and the Indian Oceans and the Mediterranean Sea, though these are not as frequent. ITIC noted that in the last decade, destructive tsunamis have occurred in Nicaragua (1992), Indonesia (1992, 1994, 1996), Japan (1993), Philippines (1994), Mexico (1995), Peru (1996, 2001), Papua-New Guinea (1998), Turkey (1999), and Vanuatu (1999), including the Indian Ocean Earthquake-Tsunami of 2005. The research on tsunamis focus on: tsunami generation, propagation and shoreline impacts; tsunami sources: earthquakes, submarine landslides and volcanoes; historical and geological identification of at-risk coastal areas; sea level, and seismic monitoring for tsunami.
Flooding

Coastal flooding is primarily caused by heavy rain events associated with storms (tropical and extra-tropical storms) and storm surges, which were discussed previously. Tropical cyclones (hurricanes) are capable of producing copious amounts of flash flooding rainfall (FEMA, 2006d). During landfall of a tropical cyclone, rainfall can commonly exceed 254 to 381 millimeters (10 to 15 inches). A slow moving storm (less than 16 kph) can generate even more excessive rainfall. Heavy rain usually occurs slightly to the right of the cyclone track and usually occurs between 6 hours before and 6 hours after landfall. FEMA noted that flooding from tropical cyclones can occur hundreds of miles from the coast putting areas which would not normally be affected by the strongest winds in great danger. Freshwater floods accounted for more than half (59 percent) of U.S. tropical cyclone deaths over the past 30 years (NWS, 2006). Over the past 30 years, 78 percent of children killed by tropical cyclones drowned in freshwater floods (FEMA, 2006d).

According to the FAO (2003) report on Vietnam, floods of long duration can cause severe social impacts during the flood. Health is a grave concern for people suffering from flooding, especially for elderly and disabled family members living in poor conditions with limited food stocks, unclean water sources, and poor sanitation. The report adds that children are most at risk from flooding and that schooling can be disrupted for long periods, especially when buildings are being repaired.

Flooding are very common in most coastal countries, especially to New Zealand. Since most New Zealand cities are situated on the coast and many are near rivers, they are at risk from sea or river flooding (NIWA, 2005c). However, a major contributor to coastal flooding in New Zealand is high tides, which can be forecast well in advance. Most rivers have protection against flooding from tides, but if a storm surge or river flood occurs at the same time as the strongest tides, serious flooding can occur. In New Zealand, the National Institute of Water & Atmospheric Research (NIWA) [2005c]) has developed a series warning of dates for the public. One of these are called “Red-Alert” dates which can be generated when a minor storm surge or river flood could cause coastal flooding because the tides are extreme for those dates. Also, a set of “Carefree” dates can be generated when there is little danger of coastal flooding unless there is a large storm surge or river flood. Predicted Red-alert and Carefree dates can be applied for other places around the world. In some places, the dates of maximum tide height will be a day or two different from those forecasted and the high tide height on some of those days may be nothing unusual.

The research on floods includes: (a) historic rainfall and flood data and risk assessment; (b) flood forecasting using coupled weather and hydrological models; (c) inundation from river- and coastal-flooding dependence on climate-flood mapping to reduce future losses.

Natural Disasters in Coastal Lowland Areas in 2005

Understanding the magnitude of disaster losses is important for a wide range of decisions, including evaluating the effectiveness of disaster mitigation and understanding trends in vulnerability.
Indian Ocean Earthquake: Tsunami 2005

In the early morning hours of Sunday, December 26, 2004, a massive earthquake measuring 9.0 on the Richter scale struck the west coast of northern Sumatra with an epicentre located some 30 kilometres under the seabed and 250 kilometres south-southwest of Banda Aceh (OCHA, 2005). The earthquake triggered powerful tsunamis reaching 10 metres in height, and these moved through neighboring parts of the Indian Ocean at over 500 kilometres an hour wrecking coastal areas in India, Indonesia, Sri Lanka, Thailand, and the Maldives, as well as in Myanmar, the Seychelles, and Somalia. With a death toll of about 350,000, the Indian Ocean tsunami was unique among large disasters in recorded human history, not only because of the sheer number of causalities and massive displacement of people, but also because of the unprecedented international donor response and the logistical challenges faced by international organizations and aid agencies in organizing and coordinating relief efforts (Athukorala, 2005).

The tsunami flooded coastal areas and destroyed homes and buildings, roads and bridges, water and electrical supplies, crops, irrigation and fishery infrastructure, and food and fuel networks. In the affected areas, economic life stopped, many businesses have collapsed, and millions of people have seen their families and communities torn apart. The disaster predominantly affected poor communities where people lived on marginal land.

A flash appeal for aid was made to the worldwide community soon after the event and is summarized below (OCHA, 2005). This appeal for aid reflected the efforts of some forty United Nations (UN) agencies and non-governmental organizations (NGOs) to plan and implement a strategic, efficient, and coordinated response to the needs of some 5 million people. There were programmes that focused on keeping people alive and supporting their efforts to recover in the agriculture, education, health, food, shelter, or water and sanitation sectors. Reaching isolated communities was a serious challenge because of the destruction of transport infrastructures and communication systems and required the establishment of complex logistics and operations platforms. A “Flash Appeal” focused on supporting people in Indonesia, the Maldives, Myanmar, the Seychelles, Somalia, and Sri Lanka from January until the end of June 2005, and called for U.S. $977 million to fund the critical work. Table 1 shows the breakdown of financial requirements by country and sector.

<table>
<thead>
<tr>
<th>Sector</th>
<th>Indonesia</th>
<th>Maldives</th>
<th>Seychelles</th>
<th>Somalia</th>
<th>Sri Lanka</th>
<th>Regional</th>
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<td>66,497,000</td>
<td>8,900,000</td>
<td>10,179,418</td>
<td>166,936,146</td>
<td>352,908,700</td>
<td>976,975,467</td>
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(Source from OCHA, 2005).
The tropical cyclone impacts in United States: The tropical cyclone season in the United States during 2005 was the busiest one ever recorded (Table 2).

Table 2: The total of tropical storm with names for the 2005 Hurricane Season in the United States in comparison to 2004.

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<tr>
<td>Total of Tropical Storms with Names (TS+H)</td>
<td>28</td>
<td>14</td>
<td>10</td>
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Knabb, et al., (2006) summarized the impacts of Hurricane Katrina which hit the southern United States in August 2005. They stated that Hurricane Katrina was an extraordinarily powerful and deadly hurricane that caused catastrophic damage across a large area and inflicted a large loss of life. Katrina was the costliest and one of the five deadliest hurricanes to ever strike the United States. They noted that considering the scope of its impacts, Katrina was one of the most devastating natural disasters in the history of the United States.

Pielke (2005) stated that based on data available from the National Hurricane Center (NHC) in the United States, the top five storms ranked by total damage in 2004 dollars were: (1) Katrina, $125B; (2) Andrew, $26.5B; (3) Charlie, $15B; (4) Ivan, $14.2B; and (5) Frances, $8.9B. He also stated that simply looking at the total costs can be misleading because storms struck in the past encountered very different levels of development and population along the coast. Therefore, previous storms would cause far more damage were they to hit with today's levels of coastal development.

The Typhoon Impact in China

China suffered from storm surges, floods, rainstorms, and winds in 2005. Disasters were various, emergent, and damaged large areas. According to incomplete statistics from a division of forecast and disaster relief under China’s Meteorological Administration, the direct economic losses from meteorological disasters were high at RMB 185.6 billion (almost U.S. $23 billion), and the damage in 2005 was higher than in 2004. The typhoon disasters were severe in 2005, hitting 11 coastal provinces that all suffered from meteorological disasters; in fact, regarding economic damage, it was one of the most severe disaster years in coastal lowland area since 1949. The direct economic losses resulting from storm surges reached RMB 33 billion (almost U.S. $4.1 billion). There were nine named storms this season (Table 3) and six out of eight tropical storms landing in China belonged to powerful typhoons.

Natural Disaster Mitigation Measures and Research

The purpose of disaster mitigation in most coastal lowland area aims to identify geographic areas and development sectors that are at risk for natural disasters and to propose solutions to the development problem of natural disaster vulnerability. These solutions fall within the realm of natural disaster preparedness and natural disaster mitigation. It is impossible to prevent most natural disasters. On the other hand, natural disaster mitigation and the reduction of the effects of natural disasters on humankind and the environment are often attainable. Natural disaster mitigation measures must be incorporated into the design and implementation of all development
projects and programs in most coastal lowland areas if development is to be sustained. To optimize natural-disaster mitigation, a mix of non-structural and structural strategies must be considered. Typical non-structural natural disaster measures include: (1) disaster response including rescue and evacuation planning; (2) disaster area mapping and zoning; (3) disaster warning systems; (4) grassroots disaster preparedness training and planning; and (5) river basin planning. Typical structural natural disaster measures include: (1) reservoir and dam safety; (2) river and estuary dykes; (3) coastal and river erosion protection; (4) estuary and port dredging; (5) saltwater intrusion barriers; and (6) new flood control reservoirs. United Nations Development Programme (UNDP, 2006).

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<th>Typhoon name</th>
<th>Haiti</th>
<th>Washi</th>
<th>Matsu</th>
<th>Sanvu</th>
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FEMA (2006c) provides several measures, at the individual and community levels, to reduce the vulnerability to tropical cyclone hazards. These measures include simple construction measures, such as the use of storm shutters over exposed glass, and the addition of tropical cyclone straps to hold the roof of a structure to its walls and foundation. In addition, more complex mitigation measures can be pursued to further reduce a property's susceptibility. It is recommended that coastal homes and businesses be elevated to permit coastal storm surge to pass under living and working spaces. The adoption and enforcement of wind- and flood-resistant building codes can further reduce the vulnerability of communities to tropical cyclones. Proper land-use planning can ensure that structures are not built in the high risk areas.

Since resources are limited, it is impossible to take all of the actions needed to protect every area and its population. Therefore, careful selection and ranking of programs and projects are required to develop an optimal natural disaster mitigation strategy. NIWA (2005a) states that by combining the expertise of atmospheric and river and coastal specialists, one can identify the likelihood of extreme events; monitor and understand key elements of weather, river and coastal systems; identify vulnerable hot-spots with increased risk; and develop computer hazards models, leading to improved forecasts and warnings. Also, by working with the national and regional governments, one can translate the research and models into risk evaluation, timely warning systems, and hazard maps and provide better community planning and increased community resilience to natural hazards.

Early warning systems are an important element of natural disaster mitigation. In the context of the Indian Ocean Tsunami in 2005, the UN’s Office for the Coordination of Humanitarian Affairs (OCHA, 2005) stated that the objectives of early warning include the following: the rapid boosting of the capacities for action and planning by public authorities; and linking the available
technical capacities on natural disasters with humanitarian and emergency management capacities. Also the activities of early warning were to quickly assess the warning capacities of the region, establish interim networks, conduct regional meetings for both training and coordination, develop interim information materials, and provide necessary coordination and support. The expected impacts are the improved public confidence and security, provision of authoritative information products to the humanitarian community, and sound foundations for coordination and informed implementation of early warning systems.

After a tsunami struck the Pacific coast of Nicaragua in 1992, causing significant damage and deaths along the coastal areas of the country, there has been some progress in the region in dealing with these kinds of events. In 2003, a Hemispheric Conference on Early Warning was held in Antigua, Guatemala (ISDR, 2005). This Conference allowed the region to prepare for the Second International Conference on Early Warning (EWC-II: http://www.ewc2.org) that took place later in 2003 which led to the creation of the “Central American Program for Tsunami Warnings.” After the Indian Ocean tsunami in December 2004, this issue reemerged at the regional and international levels, with renewed efforts to establish a Regional Early Warning System in Central America. In May, 2005 the Regional Workshop for establishing a “Program for a Tsunami Early Warning System in Central America” took place in Managua, Nicaragua (ISDR, 2005) and was organized by the Coordination Center for the Prevention of Natural Disasters in Central America (CEPREDENAC) and the Nicaraguan Institute of Territorial Studies (INETER). Many experts in the fields of seismology, geology, oceanography, education and training, as well as civil protection officials, members of Central American National Emergency Commissions, and international participants met in Managua to identify projects, elements, and activities that will contribute to establishing a Tsunami Early Warning System in Central America.

New Zealand’s National Institute of Water & Atmospheric Research (NIWA 2005e) lists several remote sensing techniques for collecting environmental data that have many applications. They are routinely using high resolution satellite imagery to support many natural hazard and risk studies both in New Zealand and in other countries. The imagery is used in mapping building and community infrastructure characteristics and in presenting future risk reduction initiatives. The use of satellite-derived topography allows them to map flood risk over large areas for the insurance industry. Additionally, the use of remotely sensed data is at the center of NIWA’s efforts to accurately predict weather-related hazards. They use radar data to estimate rainfall, and then use those estimates to validate the predictions of computer weather models and the resulting rainfall forecasts which are outputs from those models and an essential input into the river flow and flood forecasting (NIWA, 2005e).

NIWA (2005e) also has undertaken three main research themes on the prediction and monitoring of natural disasters: (1) understanding extreme weather systems and developing meteorological computer models to better predict extreme weather events; (2) improving the knowledge of floods and droughts, their risk in different regions, and developing river flood models; (3) understanding the dynamic nature of coastal environments, their propensity for generating extreme events, the effects of climate change, and translating this information into better warning systems, community awareness and preparedness programmes, and consistent planning and policy for coastal areas.
Vulnerability Assessment and Response Strategies

Vulnerability Assessment

According to FEMA (2006b), hazard mitigation planning is an important aspect of a successful mitigation program. Local communities use the hazard mitigation planning process to set short and long-range mitigation goals and objectives. They also state that hazard mitigation planning is a collaborative process where hazards affecting the community are identified, hazard vulnerabilities are assessed, and a consensus is reached on minimizing or eliminating the effects of these hazards. Vulnerability to impacts is a multi-dimensional concept, encompassing biogeophysical, economic, institutional, and socio-cultural aspects (Klein and Nicholls, 1999).

The Intergovernmental Panel on Climate Change’s (IPCC) common methodology defines vulnerability as “the degree of incapability to cope with the consequences of climate change and accelerated sea level rise” (IPCC and CZMS, 1991). Therefore, an analysis of the vulnerability of a coastal area or small island to climate change includes a notion of its susceptibility to the biogeophysical effects of climate change and sea level rise, as well as of its natural resilience which is greatly influenced by past, current, and future population; settlement patterns; and rates of socioeconomic change. The report states that both susceptibility and resilience determine the natural system’s sensitivity to anticipated changes. Other reports indicated that socioeconomic vulnerability is further determined by a country’s technical, institutional, economic, and cultural capabilities to cope with or manage the anticipated bio-geophysical effects and their consequent socio-economic impacts (WCC, 1994). The IPCC common methodology has helped to focus the attention of many coastal nations on climate change and has contributed to long-term thinking about the coastal zone (Dolan and Walker, 2003). On the other hand, a number of problems have been raised concerning the common methodology through the experiences of vulnerability assessment case studies. Although the common methodology has encouraged researchers to take into account the bio-geophysical response of the coastal system to sea level rise, lack of data and models for describing local coastal processes and responses have hindered detailed, quantitative impact assessments. Many case studies have carried out a simple first-order assessment by horizontally shifting the coastline landward by an amount corresponding with the sea-level rise scenario. More attention should be paid to broader socioeconomic evaluation techniques, which include traditional, aesthetic, and cultural values Bijlsma, et al., 1996).

In many industrialized countries, the main potential losses from sea level rise seem to be coastal wetlands, as well as sandy beaches in some countries. However, a change in the frequency, intensity, or distribution of extreme weather events could have implications for urban area and related capital assets in countries such as Japan, Australia, the United States, and some countries bordering the North Sea. The global vulnerability assessment (GVA) has provided estimates of the following impacts: 1) population at risk — the average number of people per year subject to flooding by storm surge on a global scale; 2) wetlands at loss — the ecologically valuable coastal wetland area under serious threat of loss on a global scale; 3) and rice production at change — the changes in coastal rice yields as a result of less-favorable conditions due to sea level rise in southern, southeastern, and eastern Asia (WCC, 1994).
Response Strategies

There is no doubt that the threat of climate change and sea level rise has focused attention on coastal zones and small islands and awakened awareness of the vulnerability of the world’s coastal regions in general and to low-lying coasts, tidal deltas, and small islands in particular. IPCC and CZMS (1990, 1992) have distinguished three groups of response strategies: retreat, accommodate, and protect. The first involves strategic retreat from or the prevention of future major developments in coastal areas that may be impacted. The second includes adaptive responses such as elevation of buildings, modification of drainage systems, and land-use changes. Both strategies are based on the premise that increases in land loss and coastal flooding will be allowed to occur and that some coastal functions and values will change or be lost. On the other hand, these strategies help to maintain the dynamic nature of coastal ecosystems and thus allow them to adapt naturally. The third strategy involves defensive measures and seeks to maintain shorelines at their present position by either building or strengthening protective structures or by artificially nourishing or maintaining beaches and dunes. This function could involve the loss of natural functions and values.

The International Strategy for Disaster Reduction (ISDR) has put forward the Hyogo Framework for action 2005-2015: Building the Resilience of Nations and Communities to Disasters (http://www.unisdr.org/eng/hfa/hfa.htm). ISDR recognizes priority areas in the reduction of the underlying risk factors for building a safer world and identifies a number of measures that will help reduce the impact of hazards on poor populations. However, to achieve the Millennium Developments Goals and reduce poverty before 2015, the world must find mechanisms that work and actively implement them.

There are many problems in the disaster deduction, such as development problems, poverty problems, and institutional problems. Development is extremely difficult to sustain when progress is repeatedly set back by natural disasters. An effective natural disaster mitigation strategy must incorporate opportunities for socio-economic development into its policy framework and its mitigation plans. There are poverty problems in coastal lowland areas in some developing countries, for example in Vietnam. The people most affected by natural disasters are the least able to cope with the effects of the disaster. While incorporating development opportunities into the disaster mitigation framework, special attention must be given to poverty reduction and hunger eradication. By soliciting the participation of the people most directly affected by natural disasters through a grassroots participatory approach, the afflicted communities will become empowered and share a sense of ownership of the projects they have developed. This empowerment and self-determination are the foundations of sound and sustainable socio-economic development. In natural disaster deduction, people also aim at the institutional problems and provide an opportunity for the development of institutions that will coordinate, manage, and implement disaster mitigation programs and projects. These institutions will operate on every level, from the local level in the hamlet and commune up to the central government level of a state.
Conclusions

1) Ninety percent of all natural disasters are caused by weather, climate, and water worldwide.
2) The total damage due to weather disasters reached a historic level in 2005.
3) Severe natural disasters are becoming more frequent and the effects are becoming more devastating on coastal lowland areas.

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Natural Disasters and Their Mitigation for Sustainable Agricultural Development

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Abstract

Natural disasters play a major role in agricultural development and the economic cost associated with all natural disasters has increased 14-fold since the 1950s. Natural disasters are classified into hydro-meteorological and geophysical disasters. Definitions of various types of hydro-meteorological disasters such as floods, droughts, cyclones, forest fires, and heat waves were presented. Evidence available from different parts of the world showed that there is a rising trend in the occurrence of natural disasters from 1950 to 2005. Impacts of natural disasters on agriculture, rangeland, and forestry were described. Environmental degradation is one of the major factors contributing to the vulnerability of agriculture, forestry, and rangelands to natural disasters because it directly magnifies the risk of natural disasters. Traditional definitions of sustainable development focussed on balancing agricultural productivity and environmental concerns. Today, however, it is important that the idea of sustainable development be extended beyond the notion of minimizing environmental impact; it should address issues such as managing vulnerability and enhancing the capacity to adapt and respond to natural disasters. In this sense, the sustainable agricultural development matrix should include a component of disaster risk management and reduction. There is an urgent need to mitigate the effects of hydro-meteorological disasters through the improved use of climate and weather information and forecasts, early warning systems, and appropriate methods of land management and natural resources.

Introduction

Agriculture is a complex system, within which changes are driven by the joint effects of economic, environmental, political, and social forces (Olmstead, 1970; Bryant and Johnston, 1992). It is very well known that agriculture is inherently sensitive to climate conditions and is among the sectors most vulnerable to weather and climate risks.

One of the major development issues in agricultural meteorology, which is also linked to humanitarian aid, are natural disasters which have a major impact on agricultural productivity since the economic cost associated with all natural disasters has increased 14-fold since the 1950s.

According to statistics in the Emergency Events Data base (EM-DAT), compiled by the U.S. Agency for International Development Office of Foreign Disaster Assistance (USAID/OFDA) and the Center for Research in the Epidemiology of Disasters (CRED), the number of weather-related natural disasters has risen sharply during the past 50 years (CRED, 2000). The incidence of weather-related disasters per decade has risen from approximately 100 to 1,600 events during
the past 50 years in less developed countries, with the number of people impacted or killed per
decade rising steadily from 15 million during the 1950s to four billion during the 1990s. These
trends are a result of changes in the nature of natural hazards and demographic factors bringing
greater numbers of people into harm’s way.

During the past 4 decades, natural hazards such as droughts, floods, storms and tropical cyclones,
and wildland fires have caused major loss of human lives and livelihoods, the destruction of
economic and social infrastructure, as well as environmental damages. Höppe (2007) showed
the development in the number of great natural disasters (causing billion dollar losses and/or
thousands of fatalities) since 1950 (Figure 1), which is broken down into the different perils:
floods, windstorms, geophysical disasters (earthquakes, tsunamis, volcanic eruptions) and other
weather-related events (heat waves, forest fires, droughts). Figure 1 clearly shows a steep
increase in the number of such events. Deaths since the 1950s increased 50 percent each decade,
whereas the corresponding population growth rate was only 20 percent (Kreimer and
cumulative number of casualties at 2 million with 182 million people becoming homeless.

![Great Natural Disasters 1950 – 2005](image)

Figure 1. Development of the number of Great Natural Disasters between 1950 and 2005
(Source: Höppe, 2007).

Losses from natural disasters have increased dramatically (Höppe, 2007). In the second half of
the 20th century the number of large natural catastrophes doubled and yearly damages in
monetary terms increased by more than a factor of six (Munich Re, 2006). From 1980 through
2003, the economic costs of all weather-related natural disasters totaled $1 trillion, divided
approximately 40/60 between wealthy and poor countries, respectively (Munich Re, 2004).
Although all losses have increased in absolute terms, the rise in the relative incidence of weather-
related events (such as wildfire, extreme temperature episodes, and epidemics) compared to non
weather-related ones (such as volcano eruptions or earthquakes) is particularly notable (Vellinga, et al., 2001).

As Figure 2 shows, at the global level there has been an exponential increase in both overall economic and insured losses (both adjusted for inflation) since the 1950s, reaching a record level in 2004, which was topped again by new loss records in 2005. In 1995, the year of the Kobe earthquake in Japan, record losses of about U.S. $178 billion were recorded, the equivalent of 0.7 percent of global gross domestic product (Munich Re, 2002). The largest loss from a single event in history occurred in 2005, caused by Hurricane Katrina, with overall economic losses of U.S. $125 billion and insured losses of U.S. $60 billion.

Models of future changes in extreme weather events predict particularly large impacts in the developing world from flooding and drought as well as a likely increase in tropical cyclones. The impacts on the agricultural sector are projected to be more intense because developing countries are often closer to the margin of tolerance for temperature and precipitation changes (drought as well as flooding). According to a global insurance industry group studying the issue, economic costs associated with weather-related events are projected to triple to $150 billion/year by the year 2020 (UNEP and Innovest, 2002).

Impoverished people are more exposed to natural disasters because they tend to live in marginal areas and depend on high-risk, low-return livelihood systems, such as rain-fed agriculture, and face many sources of economic vulnerability including limited physical infrastructure.
Environmental degradation and the destruction of natural barriers is one of the major factors contributing to the vulnerability of agriculture, forestry, and rangelands.

In order to ensure sustainable agricultural production and assure the livelihood of millions of people, especially in the developing countries, a better understanding of the natural disasters that impact agriculture, forestry, and rangelands is essential. Awareness of the need to give greater attention to disaster mitigation, preparedness, and management has been growing among decision makers. Pre-disaster preparedness now forms an integral part of national development planning in many countries.

Agriculture and Natural Disasters

Agriculture and the rural sector, as a source of food, raw materials, employment, and markets have crucial backward and forward linkages with virtually every other part of the economy. In fact, the poorer the country, the larger the share of agriculture in terms of gross domestic product (GDP), total employment, and exports. Rural poverty is one of the key factors that shapes the risk to natural disasters. The situation is quite disturbing in the Least Developed Countries (LDCs) since agricultural production has not kept pace with population growth in the LDCs as a whole. Although agricultural output in 1990-99 rose at an annual average rate of 2.5 percent, exceeding the rate of 1.6 percent in the previous decade, in per capita terms there was virtually no increase in output, even a slight decline occurred (IFAD, 2001). While more than 25 LDCs experienced negative per capital growth rates during 1990-99, only five countries had positive growth.

IFAD (2001) and World Bank (1997) estimate that about three quarters of the extreme poor currently live in rural areas and depend on agriculture and related activities for their livelihood. Even under high assumptions of economic development and rural-to-urban migration, 60 percent of the extreme poor are likely to be in rural areas in 2020 and 50 percent in 2035. Hence the implication is that low agricultural productivity combined with extreme poverty makes the populations living in LDCs the most vulnerable to natural disasters. Disruption of economic activity and diversion of government funds to prepare for and recover from natural disasters constrains development.

According to UNISDR (2003), the economic impacts of natural disasters are greater in poorer nations; the costs of natural disasters between 1985 and 1999 equaled 13 percent of GDP in the poorest countries versus only two percent in the wealthiest countries. In a striking illustration of the potential adverse impacts of extreme weather events, the Honduran prime minister stated that Hurricane Mitch – which killed up to 20,000 Central Americans in 1998 – set the country’s economic development back 20 years (IFRC/RCS, 2003). Losses in Honduras from Hurricane Fifi amounted to 50 percent of GDP (Hooke, 2000).

In addressing the impacts of natural disasters, the agricultural sector has not received the attention that it deserves from the policy makers since most of the economic impacts in this sector are attributable to relatively “small” events. Often it is the large headline-catching disasters that receive the attention of the public and policy makers. In the words of Swiss Re (2002), “unspectacular climatic anomalies, which the general public perceives as ‘unusual,’
rather than ‘catastrophic’ weather conditions, can cause losses on a scale normally associated with natural catastrophes.” The cost of coping with such climatic anomalies is rising because of a combination of changes in the nature of natural disasters and the increasing vulnerability of society to these disasters (IPCC, 2001). Costs not absorbed by national governments, foreign aid, or insurance fall on the poor farmers.

The poorest in the rural areas occupy the most marginal lands and this forces people to rely on precarious and highly vulnerable livelihoods in areas prone to natural disasters such as droughts, floods, etc. (UNDP, 2004). The ability to adapt to extreme weather events is lowest in the poorest segments of society and in countries where resources, information, and skills are limited; technology is often unavailable; institutions are unstable or weak; and empowerment and access to resources is inequitable (Smit, et al., 2001).

In the light of the issues mentioned above, it is important to reassess the issue of sustainable agricultural development. The traditional definitions of sustainable development focus on balancing agricultural productivity and environmental concerns. Swindale (1988) explained that sustainability conveys the idea of a balance between human needs and environmental concerns. Sustainable agricultural systems should provide for the needs of current, as well as future generations, while conserving natural resources (Natural Research Council, 1991). The enhancement of the environmental quality and careful use of the resource base on which agriculture depends is viewed as a requisite to sustained agricultural productivity (American Society of Agronomy, 1989).

Today, however, it is important that the idea of sustainable development be extended beyond the notion of minimizing environmental impact; it should address issues such as managing vulnerability and enhancing the capacity to adapt and respond to natural disasters. In this sense, the sustainable agricultural development matrix should include a component of disaster risk management and reduction.

**Natural Disasters – Definitions and Types**

In simple terms, a natural disaster is a natural event with catastrophic consequences for living things in the vicinity. But different definitions of natural disasters are often used and some of them are based primarily on loss of life. The emergencies database (EM-DAT) operated by the Centre for Research on the Epidemiology of Disasters (CRED) classifies an event as a disaster if at least “10 people are killed and/or 100 or more are affected and/or an appeal for international assistance is made or a state of emergency declared” (CRED, 2000). Clearly, for agricultural purposes only the last part of this definition is applicable.

According to a 1992 disaster training programme, United Nations (UN) defines a disaster as “a serious disruption of the functioning of society, causing widespread human, material or environmental losses which exceed the capacity of the affected society to cope using only its own resources.” With suitable interpretation of some parts, this definition could be used by agriculture.
Anderson (1990) defines natural disasters as temporary events triggered by natural hazards that overwhelm local response capacity and seriously affect the social and economic development of a region.

Susman, et al., (1983) describe disasters as the interface between an extreme physical environment and a vulnerable human population. Such definitions emphasize the fact that the socio-economic and political factors are of paramount importance in understanding why populations are vulnerable to the environment and experience disasters. According to International Federation of Red Cross and Red Crescent Societies (2003), natural disasters include hydro-meteorological disasters and geophysical disasters. The hydro-meteorological disasters include landslides/avalanches; droughts/famines; extreme temperatures and heat waves; floods; hurricanes; forest/scrub fires; windstorms; and others (insect infestation and waves/surges). The geophysical disasters include earthquakes and volcanic eruptions. In this paper, only the hydro-meteorological disasters impacting agriculture, rangeland, and forestry are dealt with. Sivakumar (2005) provided a description of the definitions of each of these disasters which is given below.

A landslide is a geological phenomenon which includes a wide range of ground movement, such as rock falls, deep failure of slopes, and shallow debris flow. Although gravity acting on an overly steepened slope is the primary reason for a landslide, there are other contributing factors. An avalanche is caused when a build up of snow is released down a slope, and is one of the major dangers faced in the mountains in winter. An avalanche is a type of gravity current.

Drought is the consequence of a natural reduction in the amount of precipitation over an extended period of time, usually a season or more in length, often associated with other climatic factors (such as high temperatures, high winds, and low relative humidity) that can aggravate the severity of the event. Drought is not a purely physical phenomenon, but instead is an inter-play between natural water availability and human demands for the water supply. The precise definition of drought is made complex due to political considerations, but there are generally three types of conditions that are referred to as drought.

- Meteorological drought is brought about when there is a prolonged period with below average precipitation.
- Agricultural drought is brought about when there is insufficient moisture for average crop or range production. This condition can arise, even in times of average precipitation, due to soil conditions or agricultural techniques.
- Hydrologic drought is brought about when the water reserves available in sources such as aquifers, lakes, and reservoirs falls below the statistical average. This condition can arise, even in times of average (or above average) precipitation, when increased usage of water diminishes the reserves.

A heat wave is a prolonged period of excessively hot weather, which may be accompanied by excessive humidity. The term is relative to the usual weather in the area, so temperatures that people from a hotter climate find normal can be a heat wave if they are outside the normal pattern for a cooler area. The term is applied both to “ordinary” weather variations and to extraordinary spells of heat, which may only occur once a century.
Flood is defined as the condition that occurs when water overflows the natural or artificial confines of a stream of other body of water, or accumulates by drainage over low-lying areas. A flood is a temporary inundation of normally dry land with water, suspended matter and/or rubble caused by overflowing of rivers, precipitation, storm surge, tsunami, waves, mudflow, lahar, failure of water retaining structures, groundwater seepage, and water backup in sewer systems.

Forest fire (or bushfire in Australasia) is an uncontrolled fire occurring in vegetation more than 6 feet (1.8 meter [m]) in height. These fires often reach the proportions of a major conflagration and are sometimes begun by combustion and heat from surface and ground fires.

Tropical cyclones, hurricanes, and typhoons are regional names for what is essentially the same phenomenon. Depressions in the tropics which develop into storms are called tropical cyclones in the southwest Indian Ocean, the Bay of Bengal, the Arabian Sea, parts of the south Pacific, and along the northern coast of Australia. These storms are called typhoons in the northwest Pacific and are known as hurricanes in the Caribbean, southeast United States, and Central America.

A tsunami (Japanese for big wave in port), which is often incorrectly called a tidal wave, is a series of massive waves that occur after an earthquake, a seaquake, volcanic activity, slumps or meteorite impacts in or near the sea. Since the constant energy of the tsunami is defined by height and speed, its height increases once its speed is reduced where the wave approaches land. The waves travel at high speed, more or less unnoticed where crossing deep water, but rising to a height of 30 m and more when approaching land. Tsunamis can cause severe destruction on coasts and islands.

**Impacts of Natural Disasters in Agriculture, Rangeland, and Forestry**

Impacts from natural disasters on agriculture, rangeland, and forestry can be positive or negative. While the impacts are predominantly negative and do affect human society significantly, there are some positive impacts or benefits that can occur (Joy, 1991).

As Das (2003) explained, the impact of natural disasters on agriculture, rangeland, and forestry can be direct or indirect in their effect. Direct impacts arise from physical damage on crops, animals, and trees caused by the extreme hydro-meteorological event. The impacts may be considered in terms of short-term, temporary damage at a particular crop stage to complete crop loss. Within hours of their occurrence, natural disasters produce direct damage to agriculture in terms of total or partial destruction of farm buildings, installations, machinery, equipment, means of transport, storage as well as damage to crop land, irrigation works, dams, and destruction of crops ready for harvesting.

Disasters also cause indirect damage which refers to loss of potential production due to disturbed flow of goods and services, lost production capacities, and increased costs of production. Such indirect impacts appear progressively as a result of low incomes, decreases in production, environmental degradation, and other factors related to the disaster (Das, 2003).
Anaman (2003) pointed out that the impacts of natural disasters can also be classified as tangible or intangible. Tangible impacts are those that can be easily measured in monetary terms. Intangible impacts are often difficult to measure in monetary terms since they are not purchased or sold in well defined markets and hence direct market values do not exist, e.g., anxiety or fear of future natural disasters (Olive, 1989), inconvenience and disruption to farm work, and stress-induced ill health and human fatalities.

Many famines in pre-20th century Africa, Asia, and Europe were triggered by natural disasters, including drought, extreme cold, pests, and diseases that devastated crops and livestock (Devereux, 2000). Loss of perennial crops such as banana trees or forests has long-term consequences on the ability to generate income. In the case of agricultural income generating assets, the loss might be temporary or permanent (Charveriat, 2000). Floods make land unsuitable for agricultural production until waters recede, while hurricanes might wash out arable land or permanently increase its salinity through storm surges and flash floods. Indirect impacts include the evacuation of people in the event of cyclone landfall, disruption to households, stress induced sickness, and apprehension (Handmer and Smith, 1992; Anaman, 1996).

Poor nations suffer the most from the natural disasters. As Devereux (2000) explained, poor people are more exposed because they tend to live in marginal areas and depend on high-risk, low return livelihood systems such as rain-fed agriculture and face many sources of economic vulnerability including little physical infrastructure. The UNDP reports that 24 out of 49 least developed nations face a high risk of natural disasters. At least 6 of them have been hit by between 2 to 8 major disasters per year in the last 15 years, with long-term consequences for human development (UNDP, 2001).

While damages related with natural disasters are greater in absolute value in developed countries, GDP loss rates are 20 percent higher in the developing countries (Funaro, 1982). Beyond the direct or indirect losses, the economic consequences are of major importance given the repercussions they have on the economic development of the countries (GDP, public finances, foreign trade, price indices). Because of the important role it plays, considering the creation of national wealth and the population needs, the agricultural sector appears as a highly vulnerable one. For example, 30.9 percent of the Gross National Product (GNP) in Bangladesh was attributed to agricultural activities in Bangladesh while in Cambodia and Laos, it was 44.6 and 54.3 percent respectively. During the last El Niño in Ecuador, Vos, et al., (1999) estimated that around 12,000 workers on banana and sugar cane plantations in the lowlands temporarily lost their jobs. In Honduras, the press reported that the rate of unemployment in the immediate aftermath of Hurricane Mitch had reached an estimated 32 percent, according to the firm, Asesorias Economicos.

The economic consequences also concern the activities related to international trade, which have become indispensable because of national debt. Export agriculture, tourism, crafts, and industrial activities are assumed to bring in foreign currency that is indispensable for the equilibrium of the balance of payments.
Agricultural export products hold an even more significant place. Free zones can be affected by cyclones and floods with greater probability as they are situated in the coastal plains and on the principal deltas. In Bangladesh, the Chittagong free zone was very seriously affected by the 1991 cyclone (Normand, 1991).

**Mitigating the Impacts of Natural Disasters**

Communities that are most exposed to risk from climate extremes and natural disasters and potentially at risk from climate change, are those with limited access to technological resources and with limited development of infrastructure. Countries, especially the geographically smaller ones, cannot be expected to cope alone because each one needs to have information on the full extent and magnitude of natural disasters. Socio-economic losses cannot be entirely eliminated, but timely and appropriate mitigation measures can certainly reduce the impacts.

The Plan of Implementation of the World Summit on Sustainable Development (WSSD) held in Johannesburg in 2002 highlighted the need to mitigate the effects of droughts and floods through such measures as improved use of climate and weather information and forecasts, early warning systems, land and natural resource management, agricultural practices, and ecosystem conservation in order to reverse the current trends and minimize degradation of land and water resources. WSSD noted the need to promote the access and transfer of technology related to early warning systems and to mitigation programmes to developing countries affected by natural disasters.

**Improved use of Climate and Weather Information and Forecasts**

The interaction between weather and agricultural production is so complex (Hoogenboom, 2000) that it is not just a case of developing a simple solution and expecting farmers to implement it. Each year or season will bring a different set of circumstances and hence the farmers have to make their decisions based on each situation. Hence a participatory approach involving the representatives of the National Meteorological and Hydrological Services (NMHSs), the agricultural extension agencies, and the farmers is necessary. One basic requirement is the awareness of the influence of weather and climate parameters on sustainable agricultural production. In many cases, this awareness is acutely present and many farmers often look for intelligent, low-risk solutions. This should stimulate an interest among the farmers to evaluate the forecast products produced by the NMHSs.

In the past 2 decades, significant advances have been made in the science and applications of seasonal climate forecasting. The principal scientific basis of seasonal forecasting is founded on the premise that lower-boundary forcing, which evolves on a slower timescale than that of weather systems, can give rise to significant predictability of atmospheric developments. These boundary conditions include sea surface temperature (SST), sea-ice cover and temperature, land-surface temperature and albedo, soil moisture, and snow cover, although they are not all believed to be generally of equal importance. Climate variations, also called anomalies, are differences in the state of the climate system from normal conditions (averaged over many years, usually a 30-year period) for that time of the year. The strongest evidence for long-term predictability comes
largely from the influence of persistent SST anomalies on the atmospheric circulation which, in
turn, induces seasonal climate anomalies.

The key weather variables for crop prediction are rainfall, temperature, and solar radiation, with
humidity and wind speed playing also a role. As Doblas-Reyes, et al., (2006) explained, seasonal
climate forecasts are able to provide insight into the future climate evolution on timescales of
seasons and longer because slowly-evolving variability in the oceans significantly influences
variations in weather statistics. The climate forecast community is now capable of providing an
end-to-end multi-scale (in space and time) integrated prediction system that provides skilful,
useful predictions of variables with socio-economic interest.

Seasonal forecasts can be produced using mathematical models of the climate system. A wide
range of forecast methods, both empirical-statistical techniques and dynamical methods, are
employed in climate forecasting at regional and national levels (WMO, 2003). Operational
empirical-statistical methods, based on statistical links between current observations and weather
conditions in the future, include analysis of general circulation patterns; analogue methods; time
series, correlation, discriminant, and canonical correlation analyses; multiple linear regression;
optimal climate normals; and analysis of climatic anomalies associated with El Niño-Southern
Oscillation (ENSO) events.

Dynamical methods (used principally in major international climate prediction centers) are
model-based, using either atmospheric the General Circulation Models (GCMs) in a two-tiered
prediction system, or the dynamically coupled atmosphere-ocean GCMs. These dynamical
forecast models – an extension of the numerical methods used to predict the weather a few days
ahead – are based on systems of equations that predict the evolution of the global climate system
in response to initial atmospheric conditions and boundary forcing from the underlying ocean
and land surfaces.

The forecasts of future trends in precipitation, 3 months or more in advance, could be extremely
important to agriculture, forestry, and land management by potentially forecasting drought or
heat waves. These outlooks have strategic relevance to national policy with respect to planning
to help alleviate food shortages, lessen the impact of droughts, and provide distribution of
energy. Seasonal forecasts, provided they are reliable enough, are already being successfully
used in developed countries at the farm level to adapt seasonal crop planning (Meinke and Stone,
2005), but there is still a deficit when it comes to making such information usable for farmers in
low-input systems (Salinger, et al., 2005). However, seasonal forecasts are already being used in
developing countries for yield forecasting to support policy decision making (Hansen and Indeje,
2004) and the MARS project of the European Union, which has been extended to the African
regions (Rojas, et al., 2005).

**Early Warning Systems**

A fundamental condition for disaster preparedness is the availability of risk assessments and well
functioning early warning systems that deliver accurate and useful information in a timely and
dependable manner to decision makers and the population at risk. While natural hazards may not
be avoided, the integration of risk assessment and early warnings with prevention and mitigation
measures can stop many hazards from becoming disasters. This means that action can be taken to considerably reduce the resulting loss of life and socio-economic damages. Without doubt, a fundamental pre-condition for disaster preparedness is a well-functioning early warning system, capable of delivering accurate information to the population at risk, dependably, and in a timely manner.

There is a growing global awareness of the importance of early warning systems. During the Second World Conference on Disaster Reduction (Hyogo, Kobe, Japan, January 2005), 168 countries adopted the Hyogo Framework for Action 2005-2015 (HFA) and identified five high priority areas, of which the second stressed the need for “identifying, assessing, and monitoring disaster risks and enhancing early warnings,” as a critical component of disaster risk reduction.

From 1980 to 2005, over 7,000 natural disasters worldwide have taken the lives of nearly two million people and produced economic losses of over one trillion U.S. dollars. However, as the number of disasters and their economic impacts increased during the period, the number of fatalities was diminishing. For example, for disasters related to weather-, water-, and climate-related hazards, there has been nearly a 4-fold increase in the number of disasters and a 5-fold increase in the economic losses, but nearly a 3-fold decrease in loss of lives. This noteworthy achievement is due to several factors, one of which is the development of specific end-to-end early warning systems (Jarraud, 2006).

WMO is working with its partners at the international, regional, and national levels to improve early warning capabilities further and ensure that these systems are available to all countries, particularly those with the least resources. The scientific programmes of WMO have been vital in expanding knowledge of the climate system. The systematic observations carried out using standardized methods have provided worldwide data for analysis, research, and modelling of the atmosphere and its changing patterns of weather systems. WMO coordinates a global network for the acquisition and exchange of observational data under the Global Observing System of its World Weather Watch Programme. The system comprises some 10,000 stations on land, 1,000 upper-air stations, 7,000 ships, some 3,000 aircraft providing over 150,000 observations daily and a constellation of 16 meteorological, environmental, operational, and research satellites. WMO also coordinates a network of three World Meteorological Centres, 35 Regional Specialized Meteorological Centres, and 187 National Meteorological Centres. Specialized programmes of observations, including those for chemical constituents of the atmosphere and characteristics of the oceans and their circulations, have led to a better understanding of interactions between the domains of the climate system (the atmosphere, the oceans, the land surface, and the cryosphere) and of climate variability and change.

Over the recent years, new technologies have brought about an accelerated increase in our knowledge of the climate system. Satellites for monitoring aspects of the oceans and sparsely populated parts of the globe; ocean buoys, and expendable bathythermographs for monitoring the physical and chemical properties of the oceans; hundreds of specially equipped commercial aircraft; and manned and automatic weather stations on land, are all expanding the volume of data and contributing to knowledge base.
In relation to any kind of hazard, such as flash floods, disaster mitigation can only be successful provided that there is enough lead-time for appropriate measures to be taken, in order to save lives and to reduce the impacts. The use of numerical weather prediction (NWP) products is a way to provide an increase in the lead-times to a greater degree than could be achieved by the use of radars alone. Today, state-of-the art technologies include improved terrestrial and space-based observation systems, as well as increasingly accurate models and the necessary telecommunication means to relay observations, in near real-time, to the forecasting and warning centers. This is especially true in the area of medium-range weather forecasting, which with the development of ensemble prediction systems (EPS), permit evaluation of the uncertainty in the forecast. Such systems need to be adapted to local circumstances and to be fully utilized, in order to extend the lead-time, especially in the developing countries.

With the aim to improve flood forecasting, WMO has launched its Flood Forecasting Initiative with the objective of further improving the capacity to deliver timely and more accurate flood forecasting products and services. This is occurring through effective cooperation of the National Meteorological Services (NMSs) and National Hydrological Services (NHSs) as well as capacity building activities in collaboration with the disaster managers.

Major advances in technology, notable progress in scientific understanding, and the accuracy and timeliness of weather and flood warnings have significantly improved over the last few decades. Today the accuracy of forecasts of large-scale weather patterns for 7 days in advance is the same as those for 2 days in advance only 25 years ago (Obasi, 1998). Now forecasts up to 10 days are showing remarkable accuracy, and there is now capability to provide some skillful information on expected weather patterns several seasons in advance.

For example, early information on El Niño episodes is now allowing advanced national planning, with considerable advantage in many sectors of the economy, such as in water resources management, tourism, fisheries, and agricultural production (Obasi, 1996). In the case of the 1997-98 El Niño event, advances in El Niño related science and in monitoring the sea-surface temperatures in the Pacific Ocean, enabled scientists in the NMHSs to predict its formation longer in advance than all the previous events. With recent developments in communication technology, including use of the Internet, information on the El Niño is disseminated in a rapid and timely manner throughout the world. These have enabled many governments to take appropriate measures, stimulated international cooperation, and integrated efforts to address the associated impacts.

The accuracy of tropical cyclone track forecasts and the timeliness of warnings have been steadily improving in the past few years. Global efforts, especially within the context of the Tropical Cyclone Programme of WMO, have resulted in a noticeable improvement in the warning systems in many parts of the world and resulted in saving a lot of lives and limiting property damage. For example, the decrease in the death toll in Bangladesh, from about 130,000 to 500 caused by similar tropical cyclones in 1991 and 1994 respectively was attributed, in large part by government sources, to improvements in early warning, and evacuation systems (Obasi, 1997).
The evolving Internet has proven to be an invaluable tool in facilitating the exchange of global and regional climate monitoring and prediction information. However many users require assistance in the selection, interpretation, and application of appropriate information. Effective early warning systems coupled with community education for protective action have reduced the potential human loss from these events. Floods as a disaster also lend themselves well for preparedness measures both structural and legislative (land use laws, zoning plans, and urbanization). Preparedness of life-saving techniques and evacuation plans should be promoted actively in these high risk zones.

**More Efficient Management of Land and Water Resources**

When prolonged natural disasters such as droughts occur, the high temperatures and low precipitation in the dry lands lead to poor organic matter production and rapid oxidation. Low organic matter leads to poor soil aggregation and low aggregate stability leads to a high potential for wind and water erosion. For example, wind and water erosion is extensive in many parts of Africa. Excluding the current deserts, which occupy about 46 percent of the landmass, about 25 percent of the land is prone to water erosion and about 22 percent to wind erosion.

On the contrary, during periods of heavy rainfall, eg., during cyclones, rainfall can erode soil by the force of raindrops, surface and subsurface runoff, and river flooding. The velocity of rain hitting the soil surface produces a large amount of kinetic energy which can dislodge soil particles. Erosion at this micro-scale can also be caused by easily dissoluble soil material made water soluble by weak acids in the rainwater. The breaking apart and splashing of soil particles due to raindrops is only the first stage of the process, being followed by the washing away of soil particles and further erosion caused by flowing water. The greater the intensity of rainfall and subsequent surface runoff, the larger the soil particles carried away.

Hence it should be apparent that natural disasters have a great impact on soils and the prevailing agricultural production systems, so farm technologies and management options have to be adapted to maintain soil functions for crop production to secure sustainable agricultural production. Agricultural practices adopted in regions that are continuously prone to natural disasters such as droughts and floods can strongly impact soil functions in the short term, and farming technologies and management can play an important role in these processes. For example, improper irrigation schemes and use of irrigation water with high salt content can increase salinity of soils, making them unusable for agricultural production. Other examples are overgrazing in the Sahel zone and other semi-arid regions which for various reasons can lead to wind erosion and desertification. In temperate regions with high-input systems, heavy machinery use, often in combination with slowly developing crops and soil cover, contributes to soil compaction; which can decrease water infiltration, increase runoff, and result in water erosion.

New farm technologies and those that have been established for many generations – indigenous technologies – offer many opportunities to mitigate the impact of natural disasters. Because of the projected climate change, the optimization of farm technologies becomes even more important for the productivity of various agricultural production systems at different input levels (Sivakumar, et al., 2005). Farmers cannot only change crops and cultivars but also modify crop
management, for example, by changing the sowing date according to the expected seasonal weather. The seasonal precipitation pattern (onset of rain, duration of rainy season, and distribution during crop-growing period) is one of the most important pieces of information for farmers in semi-arid regions using rain-fed cropping, especially for low-input systems in developing countries, which enables them to adapt their sowing dates and crop selection (Stigter, et al., 2005; Ingram, et al., 2002; Mati, 2000). Matthews, et al., (1997) reported that for rice production in Asia the modification of sowing dates at high latitudes, where higher temperatures allowed a longer potential crop-growing season, permitted a transition from single cropping to double cropping in some locations, which could had a significant effect on regional production. Two shorter ripening varieties might be a better strategy than a longer maturing variety because the grain formation and ripening periods are pushed to less favorable conditions later in the season.

The ever-increasing water demand in contrast to the slow increase in water supply is leading to unsustainable water use and competition for water resources in agriculture. This trend has serious implications for sustainable agricultural development, especially in the developing countries. Proper management of water resources by application of appropriate farm technologies plays and will play a major role in both developed and developing countries in regions with limited resources for agricultural production. For example, irrigated agriculture in the Mediterranean area was introduced in ancient times and has been improved over time with experience. However, irrigation techniques have been maintained in the same way for centuries in most Mediterranean countries. Inefficient flooding irrigation systems, for example, can be still found in many areas of Spain and Egypt (El Gindy, et al., 2001; Neira, et al., 2005). Modern sprinkler and drip-irrigation systems have been introduced at great expense in some Mediterranean European regions such as Spain (MAPA, 2005). These new techniques significantly reduce water use. The productivity of irrigated crops, such as maize, in Spain has increased in the last 15 years, compared with countries like Egypt, despite the fact that the total production is lower. The differences between Spain and Egypt may have many causes, but the new engineering irrigation infrastructures that have been introduced in Spain certainly have a strong influence on the yield increases reported (ANPC, 2003).

Improved management of watersheds through establishment of water spreading, harvesting, and storage facilities as well as the use of supplementary irrigation techniques are needed to improve and develop rain-fed agriculture. Techniques such as “deficit irrigation” should be considered as an option in the next decades, or irrigated agriculture will become unaffordable (Fereres, 2005). At the same time, it is also essential to curtail losses of conveyance and on-farm use of irrigation water through appropriate measures. Guidelines need to be developed for the rational use and proper management of the vast but mostly non-renewable groundwater resources that are available in varied water qualities in huge aquifers.

**Conclusion**

According to the International Federation of Red Cross and Red Crescent Societies (2003), natural disasters are on the rise and they continue to target the world’s poorest and least-developed and there must be greater investment in disaster reduction rather than high-profile response efforts. Improved data on past disasters would help inform investment and policy
decisions and thus help secure more appropriate levels and forms of disaster prevention, mitigation, and preparedness. Historical studies would also help inform the development of appropriate methodologies for the assessment of future disasters.

Despite a long history of disasters affecting agriculture, rangelands, and forestry, comprehensive documentation of these disasters at the national, regional, and international levels has been weak; and it is important to develop mechanisms for more efficient assessment and documentation of natural disaster impacts in agriculture. A comprehensive assessment of impacts of natural disasters on agriculture requires a multi-sectoral and integral approach involving key organizations.

Priority should be given to supporting research with practical applications since research is needed to understand the physical and biological factors that contribute to disasters. Since the major impact of natural disasters is on poor farmers with limited means in developing countries, community-wide awareness and education programs on natural disasters should be a priority. Programs for improving prediction methods and dissemination of warnings should be expanded and intensified. Efforts are also needed to determine the impact of disasters on natural resources.

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**References**


Fire Weather Agrometeorology
Fire Weather Technology for Fire Agrometeorology Operations

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Abstract

Even as the magnitude of wildfire problems increases globally, United Nations agencies are acting to mitigate the risk of wildfire disasters to members. Fire management organizations worldwide may vary considerably in operational scope, depending on the number and type of resources an organization manages. In any case, good fire weather information is vital. This paper describes an approach for introducing fire weather/fire danger-rating technology into fire agrometeorology operations, based on the collective experience of the United States, Canada, and Australia. A prototype fire weather forecasting system is presented, which has produced fire weather products for various parts of the world on a trial basis.

Introduction

The interaction between wildfire and demographic trends worldwide poses potentially serious consequences to human and ecosystem health, biodiversity, and global biogeochemical cycles. Smoke from large wildfires can impact not only local inhabitants, but also distant downstream populations across international boundaries. The Food and Agriculture Organization (FAO) and other United Nations (UN) agencies recognized the need for international collaboration to manage wildland fire globally, whether it occurs naturally or as a land management application (Framework for the Development of the International Wildland Fire Accord, 22 June 2004). FAO facilitates international agreements which countries use to assist each other in wildfire emergencies, and also supports countries in the development of fire management and preparedness programs.

Fire management organizations may vary considerably in size and level of sophistication, but they all require good weather and climate information commensurate with their needs. Even before any fire occurs, fire managers monitor the weather, because it determines the ignitability of vegetation. Fire management needs for weather and climate information are very similar to agricultural management requirements. This paper suggests how agrometeorology operations may be modified to service fire management needs.

Regional Fire Networks

By direction of the UN International Strategy for Disaster Reduction and the Inter-Agency Task Force for Disaster Reduction, the Global Fire Monitoring Center (GFMC) at Freiburg University, Germany, has been facilitating the establishment of regional wildland fire networks since 2002,
with the ultimate goal of confederating a global wildland fire network (Figure 1). The networks organize members to share resources and expertise for wildland fire management. Some of the regional networks formed on their own initiative, and were solicited to join the global wildland fire network. Others were encouraged to organize with the assistance of the GFMC. Table 1 lists the nations that populate the various regions, although not all regions necessarily have formal agreements that bind the members.

![Figure 1. Regions within the UN-ISDR/GFMC Global Wildland Fire Network, from http://www.fire.uni-freiburg.de/GlobalNetworks/FAO-COFO-GFMC-March-2005.jpg.](image-url)

Note the substantial variation in size of the regions. Some countries are members of multiple regions. The largest regions may include a vast range of climatic conditions and ecosystems, which define the biological and geophysical nature of the fire management problem. However, the regionalization described by the Global Wildland Fire Network provides an initial framework for organizing fire agrometeorology services, where those services are desired but either do not exist or are unacceptably deficient. In any case, a fire weather support function must be tailored to customer needs for information, which may also vary considerably from region to region.
Table 1. Regional memberships in the Global Wildland Fire Network, as suggested by the Global Fire Monitoring Center. Not all memberships are formalized.

<table>
<thead>
<tr>
<th>Region</th>
<th>Countries Included in GFMC Grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southeast Asia</td>
<td>Indonesia, Malaysia, Philippines, Thailand, Cambodia, Lao, Myanmar, Singapore, Vietnam</td>
</tr>
<tr>
<td>North East Asia</td>
<td>China, Japan, Korea, Russian Federation</td>
</tr>
<tr>
<td>Sub-Sahara</td>
<td>Benin, Central African Republic, Cote d’Ivoire, Ethiopia, Ghana, Kenya, Lesotho, Madagascar,</td>
</tr>
<tr>
<td></td>
<td>Mozambique, Namibia, Senegal, South Africa, Sudan, Zambia, Zimbabwe</td>
</tr>
<tr>
<td>Central Asia</td>
<td>China, Kazakhstan, Mongolia, Russian Federation</td>
</tr>
<tr>
<td>Baltics</td>
<td>Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Norway, Poland, Russian Federation, Sweden,</td>
</tr>
<tr>
<td></td>
<td>Belarus, United Kingdom</td>
</tr>
<tr>
<td>Southeast Europe</td>
<td>Albania, Bulgaria, Croatia, Macedonia (Former Yugoslav Republic)</td>
</tr>
<tr>
<td>Mediterranean</td>
<td>Albania, Algeria, Croatia, Cyprus, Greece, France, Italy, Portugal, Spain</td>
</tr>
<tr>
<td>North America</td>
<td>Canada, Mexico, United States</td>
</tr>
<tr>
<td>Mesoamerica</td>
<td>Mexico, Costa Rica, Guatemala, Belize, El Salvador, Honduras, Nicaragua, Panama, Cuba</td>
</tr>
<tr>
<td>South America</td>
<td>Argentina, Brazil, Colombia, Chile, Ecuador, Paraguay, Peru, Uruguay, Venezuela</td>
</tr>
<tr>
<td>Australasia</td>
<td>Australia, New Zealand, Fiji</td>
</tr>
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</table>

Weather Information Requirements for Fire Management

The weather information requirements for fire management essentially depend on the level of sophistication of the fire management organization. The United States has developed one of the most sophisticated fire weather information systems in the world; because the supported fire management organizations have varied and complex data needs that span a broad range of temporal and spatial scales. Federal fire management planning functions consider the spatial variability of wildfire potential on continental and seasonal scales, usually well before the start of fire season. During fire season, fire management focuses more on regional and local scales and diurnal to daily trends. When a wildfire occurs, planning drills down to the immediate environs of the fire and its potential reach in a 2- to 3-day period, including the impact zone of smoke effects. Recently, fire weather prediction tools have routinely included mesoscale meteorological models that require supercomputing to support air quality and fire behavior prediction.

U.S. National Fire-Danger Rating System

On a national scale, the U.S. fire weather information requirements are driven principally by the National Fire-Danger Rating System (NFDRS) introduced by the USDA Forest Service in the 1970s (Deeming, et al., 1972, 1977). The basis for the NFDRS is a semi-empirical physical model that relates wildland fire characteristics to vegetation, topography, and weather (Rothermel, 1972). The system describes three attributes of a fire that comprise essential
information for its management: ignitability, rate of spread, and energy release rate. Fire managers use this information to mitigate high fire risk and plan an appropriate response in the event of fire occurrence. Figure 2 illustrates the relationship of the fire characteristics to the variables that describe the fire environment, including weather.

Weather Relationship to Fire Potential

Figure 2 is a flowchart that shows how the NFDRS obtains fire characteristics (bottom tier of boxes identified as “Output”) from the fire environment variables, mostly surface weather data (top tier of boxes, “Input”). Note that non-weather factors such as fuel type, topographic slope, and latitude are also required. Two types of weather data include an hourly observation of

![NFDRS Structure Diagram](image)

Figure 2. The U.S. National Fire-Danger Rating System (NFDRS) relates weather, fuel, and topographic characteristics to potential fire characteristics (Schlobohm and Brain, 2002).

weather conditions at 1300 Local Standard Time, nominally the time of day when fire potential is greatest. The second type of weather data is a 24-hour summary of weather variables, namely precipitation amount, maximum and minimum temperature and relative humidity, and precipitation duration (length of precipitation period). The system uses the data to estimate dead
fuel moisture content in various fuel size categories. High moisture contents tend to inhibit the ignition and spread potential of fires. The heat release rate is also affected, because when moisture is present, it acts as an energy sink until it is vaporized.

**U.S. Application of Fire-Danger Rating in Fire Management**

Information from the NFDRS has various uses in U.S. wildland fire management (Schlobohm and Brain, 2002). For example, the Energy Release Component or the Burning Index may be used to determine the staffing level of a local unit. If the indices indicate high fire danger over an extended area, coordinated staffing and/or resource sharing might be considered. The Spread Component may be used in presuppression planning to determine an appropriate suppression response. In this case, good wind information is essential, because the Spread Component increases nonlinearly with wind speed. Many fire organizations use the NFDRS to inform the public of fire danger in recreational areas. The indices for any given day determine an adjective fire danger level, e.g., low, moderate, high, very high, or extreme. The public is educated about expected behaviors on affected lands, given the danger level.

**Canadian and Australian Fire-Danger Rating Systems**

Although the NFDRS was designed to be a national system, it is not uniformly applied in the United States. The NFDRS is sometimes criticized because of its complexity. Some fire organizations in the northeast favor the somewhat less demanding Canadian Fire Weather Index component of the Canadian Fire-Danger Rating System (see the Web site at http://fire.cfs.nrcan.gc.ca/research/environment/cffdrs/fwi_e.htm). The structure of the Canadian system is similar to the NFDRS, but it doesn’t share the same theoretical underpinnings and data requirements (Figure 3). Note the sequential processing starting with weather data, from which fuel moisture content is estimated, which in turn yields fire behavior indices. Australia’s McArthur Forest Fire-Danger Rating System not only shows similarities to both U.S. and Canadian systems, it utilizes the U.S. Keetch-Byram Drought Index (Figure 4). It might be possible to meet user needs with a subset of components from existing fire-danger rating systems.

**Weather Data Requirements for Fire Management Support**

The examples of the U.S., Canadian, and Australian fire-danger rating systems provide, at a minimum, the means to determine where the high potential ignition areas are, given the appropriate weather information. In all three systems, this potential is dependent on the moisture content of fine fuels, which in turn depends on air temperature, relative humidity, and either precipitation amount or occurrence. Once a fire starts, its potential growth rate can be estimated with the addition of wind data. The weather data requirements for these tasks are very similar to the data requirements for agricultural applications (Motha and Sivakumar, 2001).
Figure 3. The Fire Weather Index component of the Canadian Fire-Danger Rating System is structurally similar to the U.S. NFDRS.

Figure 4. Flowchart of the data processing and sub-models of the Australian McArthur Forest Fire-Danger Rating System (San-Miguel-Ayanz, et al., 2003). The flow proceeds from the bottom up, which is opposite from Figures 2 and 3.
A Fire Weather Forecasting System Prototype

The Experimental Climate Prediction Center (ECPC) at Scripps Institution of Oceanography features a fire weather/fire-danger prediction system co-developed with the USDA Forest Service Forest Fire Laboratory in Riverside, California. ECPC routinely generates regional and global fire weather forecasts for the United States on a daily basis (Roads, et al., 2001). It has also generated fire weather forecasts for other regions of the world, including Africa, South America, the Middle East, and Europe, on a trial basis.

ECPC determined that its weather models are relatively useful at predicting the Fosberg Fire Weather Index (FFWI), which is different from the Canadian Fire Weather Index. The FFWI is a modification of the NFDRS Burning Index (BI). Unlike the BI, however, the FFWI does not require fuel information, because it assumes the fuel characteristics of fine dead vegetation. The BI is calculated from a combination of the NFDRS Spread and Energy Release Components (Figure 2), and is a theoretical indicator of expected flame length.

The efficient distribution of the ECPC forecast products is not a trivial task. In the course of a day, numerous maps for different regions and different weather and fire-danger variables are generated. ECPC serves these highly perishable products with ease and efficiency through the Internet. Figure 6 shows a sample menu of items offered by ECPC on the Web.

There are many products offered by the ECPC on the Web, which are generated by variants of a spectral weather model originally developed by the U.S. National Weather Service. For each of the three weather models, there are forecast maps of over 10 variables, provisionally offered in 6-hourly, weekly mean, monthly mean, and seasonal mean timeframes. However, only a subset of these products is available at the present time, commensurate with user demand.

**Summary and Conclusions**

A global need exists for fire weather information to support fire management activities. These activities may differ in the level of sophistication from one organization to another, but they all depend on the best weather information available, commensurate with their needs. Various United Nations agencies, including the FAO and the Inter-Agency Task Force for Disaster Reduction, have instituted programs to facilitate a coordinated approach to fire management for the mutual benefit of all participants. Under the direction of the Interagency Task Force (IATF), the Global Fire Monitoring Center at Freiburg University has identified regional fire weather networks. These may be considered initially as regional fire weather networks for the purpose of starting up fire agrometeorology services, where none exist or current services are marginal at best.

In consideration of existing fire weather technologies, this paper has presented a limited view of three examples, the U.S., Canadian and Australian fire-danger rating systems. Nevertheless, these systems exemplify fire management technology at the highest level of sophistication, given their histories and degree of operational maturity. If fire-danger technology is desired where it doesn’t exist, a startup fire weather service might begin with a subset of the U.S., Canadian or
Australian fire-danger rating system. The Canadian system has been successfully adapted in other parts of the world (e.g., de Groot, et al., 2005).

The fire weather forecasting system prototype at the Experimental Climate Prediction Center demonstrates the possibilities of instituting a versatile fire weather forecasting system that can be tailored to a variety of regional needs, given adequate resources. The modeling methodology that ECPC is testing makes it possible to generate fire weather/fire danger forecasts for virtually anywhere in the world, although ECPC is not an operational forecast center. Its primary function is research and development of weather models. Generation of fire weather/fire danger forecast products requires a full-time commitment, the dimensions of which would depend on customer requirements. Weather forecast centers with sufficient advanced computing resources are logical candidates to provide fire weather/fire danger forecasts. The Australian Bureau of Meteorology recently submitted a proposal to the World Weather Research Programme of the World Meteorological Organization inviting the opportunity to host a fire weather forecast demonstration project. The Bureau’s experience in fire weather forecasting and support of a sophisticated fire management community easily qualifies them for the task.

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References


Workshop Conclusions

and

Recommendations
Workshop Conclusions and Recommendations

M.V.K. Sivakumar and R. Stefanski

The participants were organized into three breakout groups based on the following topics:

1) Assessment of agrometeorological criteria for conservation and management of natural and environmental resources;
2) Agrometeorological themes for efficient management of natural resources for sustainable agricultural development; and
3) Agrometeorological guidelines for conservation and management of natural resources.

The following conclusions and recommendations were then compiled from the output of the groups and were presented to the workshop by each breakout group.

Conclusions

1) Effective conservation and management of natural and environmental resources are considerably impacted by climate variability, climate change, increasing energy costs, environmental regulations, changing demographics, and access to appropriate technologies.

2) Developing better modeling and forecasting tools to provide users with greater flexibility in decision making is significant both for the scientific issues involved as well as for the practical relevance of the results.

3) The impact of weather and climate on conservation and management of natural and environmental resources is increasingly viewed in the context of risk management.

4) Land degradation, water resource management, drought, and fire (forest, bush, and grass) are the main topics that agrometeorologists need to focus on in the future. Weather extremes and natural disasters, combined with explosive population growth, seriously challenge the future quality-of-life for all, therefore effective coping strategies for natural disasters are essential.

5) The major agrometeorological themes in managing natural resources for sustainable agricultural development include: preparedness (best practices), monitoring (data), assessment (vulnerabilities), mitigation, and adaptation.

6) Good stewardship of the land is essential for sustainable agriculture. There is a growing recognition that land degradation is a major world-wide issue and there is a need for more complete evaluation of the expansion of degraded land around the world.

7) There is a lack of effective communication in exchanging ideas among multidisciplinary sciences concerning the management and conservation of natural resources.
Recommendations

1) To provide adequate and appropriate weather and climate information from the meteorological observation networks to users on a near real-time basis, especially for developing risk management strategies to cope with climate variability and climate change. To integrate station, gridded, and remotely sensed data in order to improve model accuracy and provide more useful products.

2) To place high priority on free and open access among disciplines for data, results, findings, and management successes to increase cost-effectiveness and to disseminate rapidly time-sensitive information regarding meteorological phenomena and its application for land resource management.

3) To provide greater emphasis on the quantification of natural and environmental resources by developing and providing access to hydro-meteorological and geographical databases and environmental impacts.

4) To promote a long-term perspective of resource use for sustainable agricultural development rather than short-term measures since there is a finite capacity of natural resources and the environment, especially under changing demographics.

5) To collate knowledge-intensive and locally-adapted best management practices and technologies and make them available to users while taking into consideration long-term conservation of natural resources, increasing energy costs, and knowledge of local weather and climate.

6) To develop and implement agrometeorological information systems in close collaboration with the user communities, e.g., development of fire-weather systems.

7) To encourage the development of robust models that provide probability based results that can be used for risk assessment and management.

8) To re-evaluate the current strategies for conservation and management of natural resources and incorporate preparedness and mitigation plans to effectively cope with the increasing frequency of extreme events and natural disasters and their impacts on agriculture.

9) To improve technology transfer, especially to Least Developed Countries (LDCs).

10) To promote and improve the interactions between the NMHSs and Ministries of Agriculture and other natural resource organizations and user groups.

11) To ensure that risk and vulnerability assessments are carried out at an appropriate scale and incorporate socio-economic factors along with the agrometeorological analysis. To
include analyses of economic values of the information products and services provided by the agro-meteorology community.

12) To promote the use of an integrated risk-management framework that takes into account preparedness, monitoring, assessment, mitigation, and adaptation and encourage the development of robust models that provide probability based results. To develop risk management scenarios to deal with the environmental, economic, and societal impacts of more frequent and extreme natural disasters on regional scales throughout the world.

13) To integrate comprehensive data monitoring/data management systems for managing land use and mitigating land degradation.

14) To validate/reemphasize the current agriculture zoning and practices in response to climate variability and change. To develop policies and promote legislation to protect against overuse of lands. To develop appropriate triggers for identifying critical thresholds where different cultural practices should be implemented.

15) To provide appropriate decision making information to users that is tailored to their needs through rapid dissemination such as internet-based, early warning, and decision-support systems that also include geographic information. To ensure that feedback mechanisms are constantly evaluated and updated.

16) To develop and promote the use of operational fire-weather/danger-forecasting systems (i.e., currently used in Hawaii) that are relatively inexpensive and that can quickly disseminate a broad range of information for more informed management decisions and for better organizational efficiency.

17) To increase the outreach and education regarding the impacts of climate variability and weather extremes on land conservation while recognizing the need for that land to support an ever increasing population.
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