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CONTENTS

The papers contained in these proceedings reflect the author(s) interpretations of the data sets, inferences, and interpretations presented therein. Editing of these papers by the compilers of the proceedings consisted largely of formatting for consistency of presentation.

LONG-TERM CHANGES IN PEAK SNOWPACK ACCUMULATIONS ON ARIZONA WATERSHEDS

Peter F. Ffolliott[1]

Field observations and computer predictions indicate that the magnitudes and timing of peak snowpack accumulations in the western states might be changing, with magnitudes less and timing earlier in the snowmelt-runoff season. These changes have often been attributed to changes in the regional climate. Because snowmelt-runoff is a major source of streamflows from Arizona watersheds (Ffolliott and Baker 2000, Baker and Ffolliott 2003), a study of the long-term magnitudes and timing of peak snowpack accumulations has been initiated to determine if the reported changes in snowpack conditions is also occurring in this state. Data sets representing measurements from the network of snow courses maintained by the Natural Resources Conservation Service (formerly the Soil Conservation Service) and their cooperators are the basis for this study. Preliminary results of the study are presented in this paper.

SOURCE DATA

Source data represent nearly 70 years of snowpack measurements and, therefore, are the longest record of snowpack conditions in the state. It should be noted, however, that these data are biased because of the selected locations of the snow courses, varying number of snow courses in the network, snowpack measurement intervals, and changes in measurement technique.

The snow courses were established to provide an index of snowpack magnitudes (in inches of water equivalent) to predict snowmelt-runoff volumes, not necessarily to represent the average snowpack conditions on the watershed in question. Therefore, the snow courses were located in accessible areas to facilitate obtaining the necessary snowpack measurements and they were situated on sites that were relatively flat, protected from the prevailing wind to minimize blowing of snow, and would (hopefully) retain a measurable snowpack throughout the snowmelt-runoff season.

The changing number of snow courses through time is another issue. The first snow courses in Arizona were established in the middle 1930s. Additional snow courses were added in the following years, while other snow courses were eliminated through time because of a lack of (statistical) significance in contributing to the regression models for predicting snowmelt-runoff volumes. The results presented in this paper, therefore, must be interpreted within the framework of this variable sample.

Water equivalents on the snow courses were originally measured with a snow tube on a bi-weekly basis on the beginning and mid-point of a month beginning in January and continuing to the end of snowmelt-runoff season. Due to unfavorable weather conditions, the availability of personnel (especially cooperators), and other uncontrollable factors, however, this bi-monthly schedule could not always be maintained. Snowpack measurements at the prescribed bi-weekly time interval were not always possible as a consequence.

Measurements of water equivalents with a snow tube have been largely replaced in recent years by transmitting data collected on selected snow courses by pressure pillows (snow pillows) to a central processing center by SNOWTEL (the Snow Data Telemetry System). The data obtained by this method represent the real-time conditions on a snow course and, importantly, are available to be accessed and retrieved for almost analysis at any time (Brooks et al. 2003).

The magnitudes and timing of peak snowpack accumulations, therefore, are more accurately estimated with these data sets, therefore, than was possible with the earlier estimates obtained with a snow tube on a bi-weekly basis.

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ANALYTICAL PROCEDURES

The magnitudes and timing of peak snowpack accumulations on snow courses with the longest continuous records were averaged for 10 year intervals (that is, 1930, 1940, 1950, etc.) for analysis. However, there were less than 10 years of record in the 1930 decade because the first snow courses were established in the middle 1930s, while the record for the 2000 decade remains incomplete. Another consideration of importance in analyzing the data sets centered on the varying number of snow courses in the sample for a specified snowmelt-runoff season. The sampling frame was not constant throughout the study period because of the establishment of additional snow courses and the discontinued monitoring of some of the established courses through the years of data collection.

Snow courses selected for analysis in this preliminary study were all located on watersheds within the major river basins in Arizona including the Gila, Salt, Verde, San Francisco, and Little Colorado. They ranged in elevations from about 6,500 to over 8,500 feet, an elevational strata representing the historically expected snowfall region in the state (Beschta 1974). While some of these snow courses were situated on sites with a forest overstory, most of the courses had been established in openings adjacent to a forest structure.

of conserving and augmenting the states water supplies to accommodate the growing population of people (Fox et al. 2000).

A steady decline in the magnitudes of peak snowpack accumulation between the decades of 1960 and 2000 is indicated in figure 1, reflecting about a 50 percent reduction in water equivalents for the period. This reduction is similar to that reported for other western states. Whether this decline will continue into the future is open to conjecture.

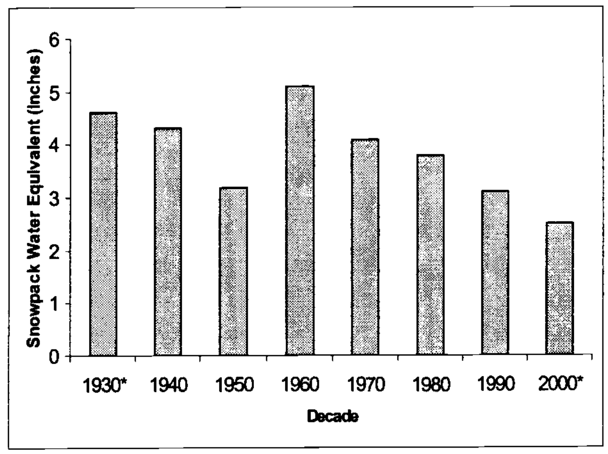

Figure 1. Magnitudes of peak snowpack accumulations on selected snow courses. Average water equivalents for the 10 year intervals of 1930 to 2000 are shown. *Less than 10 years of record.

RESULTS AND DISCUSSION

Magnitudes of Peak Snowpack Accumulations

The magnitudes of peak snowpack accumulations (in inches of water equivalents) for the study period are presented in figure 1. The magnitudes prior to 1950 are likely to be indicative of the A historical variability in peak snowpack accumulations normally expected in the state.

While some of the snow courses in a sample period in this time span attained seasonal peaks on a particular date, other snow course often attained this condition either before or after that date, with the average snowpack conditions reflecting this variability. It is also important to note that the decade of the 1950s was a period of prolonged drought throughout the state. Parenthetically, it was during this drought period that the Arizona Watershed Program was initiated to intensify efforts

It should be noted that the severe drought of the 1950s is illustrated by the magnitude of peak snowpack accumulation for this decade. This drought was followed by a decade of above average precipitation, again, reflected by the high magnitude of peak snowpack accumulation for this decade. Once again, the magnitudes of peak snowpack accumulation before 1950 are likely indicative of the normal variability to be expected in the state.

Timing of Peak Snowpack Accumulations

The timing of peak snowpack accumulations areshown in figure 2. That the timing of peak snowpack accumulations is occurring earlier in the snowmelt-runoff season appears inconclusive. A clearly defined trend in the timing of peak snowpack accumulations for the study period is not shown in this figure.

Snowpacks are largely intermittent in Arizona, with alternating cycles of snow accumulation and melt. The snowpacks are also relatively shallow in comparison to other regions in the western states. Furthermore, peak snowpack accumulations in the state are likely to occur at different times in different locations through the snowfall region largely in response to the inherent elevational gradients (Beschta 1974). It could be, therefore, that the timing of peak snowpack accumulations illustrated in figure 2 is simply a measure of the expected variability.

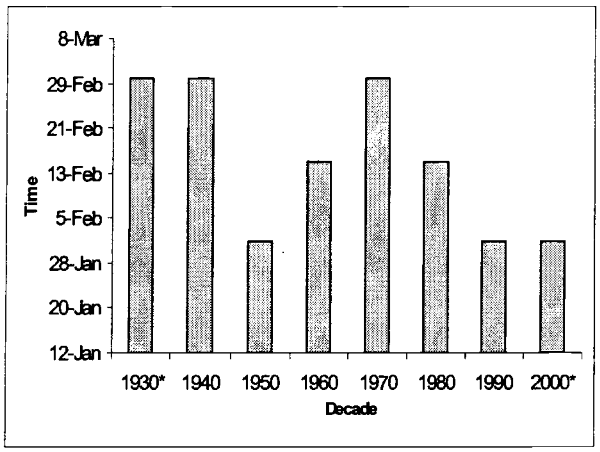

Figure 2. Approximate timing of peak snowpack accumulations on selected snow courses. Average dates for the 10 year intervals of 1930 to 2000 shown. *Less than 10 years of record.

CONCLUSIONS

The results of this preliminary study confirm (to some extent) the findings of some of the other studies in the western states of the long-term decline in the magnitudes of peak snowpack accumulations. How long the observed decline will continue into the future is unknown. The winter of 2007-2008 - which was not included in this study - produced the best overall snowfall of the preceding eight years, with the snowpacks in Arizona generally above average when the spring snowmelt-runoff season began.

The results obtained on the timing of peak snowpack accumulations are considered inconclusive by the author at this time. The variability of the snowpack conditions normally observed throughout the state might be a contributing factor to this situation. It is also unknown if a longer data set would allow a clearer picture of the timing to be obtained.

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INTERNATIONAL CO-OPERATIVE PROGRAM ON ASSESSMENT AND MONITORING OF AIR POLLUTION EFFECTS ON FORESTS: THE SIERRA ANCHA EXPERIMENTAL FOREST, ARIZONA

Boris Poff [1] and Daniel G. Neary[2]

At the end of the 2007 Fiscal Year, the Experimental Forests and Ranges (EFR) Synthesis Network Committee awarded funds to 18 sites to establish a strategic ICP Level II (described below) synthesis network in the United States. Eleven Experimental Forest were selected to be included in the network, as well as seven Long Term Ecological Research (LTER) sites. This will give the USFS R&D a ICP Level II Network starting this year, the only one in North America (see Appendix). Each site will include a NADP weather station, UV Radiation Monitors and Ozone Sensors. The Sierra Ancha Experimental Forest (EF) was chosen to be part of this network, because it is the most southern EF in the contiguous US and because it is downwind from Phoenix, Arizona, one of the nation's largest metropolitan areas.

OBJECTIVES

The main objective of the proposed network is to strengthen the role of the EFR by providing more internationally standardized data which will benefit the entire US EFR network - all 77 sites. The network will contribute to a better understanding of the relationships between the condition of forest ecosystems and anthropogenic (in particular air pollution) as well as natural stress factors through intensive monitoring on a number of selected permanent observation plots and to study the development of important forest ecosystems.

Further, the network will provide a deeper insight into the interactions between the various components of forest ecosystems by compiling available information from related studies, and in close co-operation with the ICP on modeling and mapping will contribute to the calculation of critical levels/loads and their exceedances in forest ecosystems. Ideally this will improve collaboration with other environmental monitoring programs as well and contribute to the monitoring activities to other aspects of relevance for forest policy at national and global level, such as effects of climate changes on forests, sustainable forest management and biodiversity in forests. Lastly, the network will provide policy-makers and the general public with relevant information.

The Sierra Ancha EF in particular plays three important roles in this network: (1) it is the southernmost EF in the contiguous US; (2) it is downwind from the nation's fourth largest metropolitan area; and (3) it is the driest EF in the network.

BACKGROUND

The International Co-operative Program on Assessment and Monitoring of Air Pollution Effects on Forests (ICP) was launched in 1985 under the Convention on Long-range Transboundary Air Pollution of the United Nations Economic Commission for Europe (UNECE) due to the growing public awareness of possible adverse effects of air pollution on forests. ICP Forests monitors the forest condition in Europe, in cooperation with the European Union using two different monitoring intensity levels. The first grid (called Level I) is based on around 6000 observation plots on a systematic transnational grid of 16 x 16 km throughout Europe. The intensive monitoring level comprises around 800 Level II plots in selected forest ecosystems in Europe. Currently 40 European countries and the US participate in the ICP Forests network.

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METHODS

Study Site

The Sierra Ancha Experimental Forest, located on the Tonto National Forest about 48 km northeast of Globe, Arizona, was established in 1932 as a research area devoted to studying watershed management. This 5,364-ha experimental area is typical of watershed and vegetation conditions throughout the Southwest, particularly in Arizona.

The climate, soil, and physiography are typical of much of the southwestern region, and are particularly representative of the Verde, Salt, and Upper Gila watersheds. The Sierra Ancha lies along the crest of the Sierra Ancha Mountain range and includes areas between 1,082 to 2,354 m in elevation. Vegetation types within the forest range from semidesert shrub and grassland to the pine-fir forests at higher elevations.

Climate

Precipitation averages about 850 mm at the higher elevations at Workman's Creek, 635 mm at the intermediate elevations (1,460 to 1,830 m) surrounding the headquarters, and 410 mm at the lower elevations.

Soils

Geology of the range is complex with sedimentary, metamorphic, and igneous rocks uplifted in a dome like structure. Thick formations of Dripping Springs quartzite, dissected by deep canyons or with intrusions of diabase and basalt plugs and sills are common in much of the forest. Troy sandstone occurs at higher elevations.

Vegetation

Eight vegetation types have been identified on the Sierra Ancha including, from the high elevations to low; mixed conifer, mountain park, ponderosa pine, chaparral, oak woodland, desert grassland, desert shrub, and riparian. Fifty-seven percent of the vegetation is covered by chaparral shrubs.

Research, Past and Present

Research studies on watershed management problems in woodlands, chaparral, ponderosa pine, and pine-fir forests were conducted on the sites that ranged in size from several square meters to complete watersheds comprising several thousand hectares. The Sierra Ancha is still maintained as a research site under the administration of the Rocky Mountain Research Station. Many of the earlier watershed studies have been concluded and the results published.

Set-up Considerations

One important selection criterion is that the Level II plots in a country should be located in such way that the most important forest species and most widespread growing conditions in the respective country are represented. Within the plot, the situation shall be as homogeneous as possible regarding tree species, stand type and site conditions. Whenever possible, plots should be selected that have been monitored during the last years. The great advantage of existing data on air quality and meteorological parameters from nearby stations should be taken into consideration whenever establishing Level II plots.

The plot has a minimum size of 0.25 ha. Each plot is surrounded by a buffer zone with a minimum width of 10 m, if possible. There should be no differences in the management of the plot, its buffer zone and surrounding forest, e.g, management operations should be comparable and fencing should be limited to a minimum. However, the disturbance of the monitoring activities should be minimized. Trees felled in the plot or in the buffer zone should be registered and if possible used for increment analysis. The standard Level II-plot design is shown in the appendix.

In principle, all trees in the total plot are to be included in the sample for the tree assessment, e.g, crown inventory, increment assessment. In the case that the plot has many trees in a dense stand, a sub-plot may be defined to be used for these surveys. The size of the sub-plot at the time of the installation of the plots should be large enough to give reliable estimates for theses surveys for a minimum of 20 years, preferably throughout the life of the stand.

A minimum of at least 20 trees in the sub-plot should be available in this period. The installation of a plot comprises its detailed description, including stand and site characteristics and other available information on the history of the plot, or other nearby monitoring stations.

Efforts to complete the set of data on as many plots as possible are important. The best option is to carry out all the surveys on as many plots as possible. If it is not possible to equip all plots in a country, it is strongly recommended to concentrate the continuous measurements on soil solution, meteorological parameters, deposition and ambient air quality at a smaller number of plots. These plots are best selected taking into account the need of statistical analysis.

If all measurements mentioned under points a - k (Table 1) are carried out at the same plot, this plot is then called a key plot. All countries are invited to establish at least 10% of their Level II plots as key plots. While all Level II plots contribute at a certain degree to improve the understanding of the cause-effect relationship (objective b) the key plots will provide the supplementary information necessary to fulfill objective c (to provide a deeper insight into the interactions between the various components of forest ecosystems by compiling available information from related studies).

Table 1: Surveys carried out on Level II plots

Survey	Frequency	Intensity
Crown condition	at least annually	all plots
Soil (solid phase)	every 10 years	all plots
Soil solution	continuously	part of the plots
Foliage	every 2 years	all plots
Deposition	continuously	part of the plots
Ambient air quality	continuously	part of the plots
Meteorology	continuously	part of the plots
Forest growth	every 5 years	all plots
Ground Vegetation	every 5 years	all plots
Phenology	several times per year	optional
Litterfall	continuously	part of the plots
Remote Sensing	preferably at plot installation	optional

Data Collection

The exact protocol for data collection in the US ICP Level II network is still to be determined. Once the instrumentation described below has been installed and set-up two station personnel will travel probably on a monthly basis to the Sierra Ancha EF to download the data which is collected continuously. This data includes:

Meteorology

Meteorological measurements will be taken on a continuous basis using an automated weather station described below. A NADP type wet/dry collector will also be deployed.

Water Flow

Streamflow will be measured on three supercritical, trapezoidal flumes located on the Workman Creek North, Middle and South Forks. Water yield based on stage height and flume ratings will be measured with modern electronic stage height sensors. Stream stage heights are converted to flow volumes based on hydraulic rating formulas.

Ambient Air Quality

Ambient air quality is measured by two methods: (1) a Ozone monitor measures atmospheric ozone in the concentration range 1.5 ppbv to 100 ppmv using the established technique of UV absorption at 254 nm. These data are recorded with a data logger which will be downloaded during site visits. (2) Passive samplers will collect samples for nitric oxide, nitrogen dioxide, sulfur dioxide & ammonia.

Most likely these samples will be shipped to the PSW Riverside station for testing and analysis. Again the exact protocol is yet to be determined.

Soils

Soils are evaluated every ten years (solid phase) as well as continuously (liquid phase). The solid phase evaluation will begin in 2008, after monitoring instrumentation has been installed. Soil solutions will be collected together with the other continuously compiled data and will is collected by an integrated soil and groundwater pollution monitoring unit. The sampler will collect soil water, soil gas, monitor soil moisture, temperature and conductivity, and store soil water samples in the soil until further analysis can be performed.

Vegetation

Overstory composition, understory, and forest floor will be determined on the established monitoring site at given time intervals (Table 1).

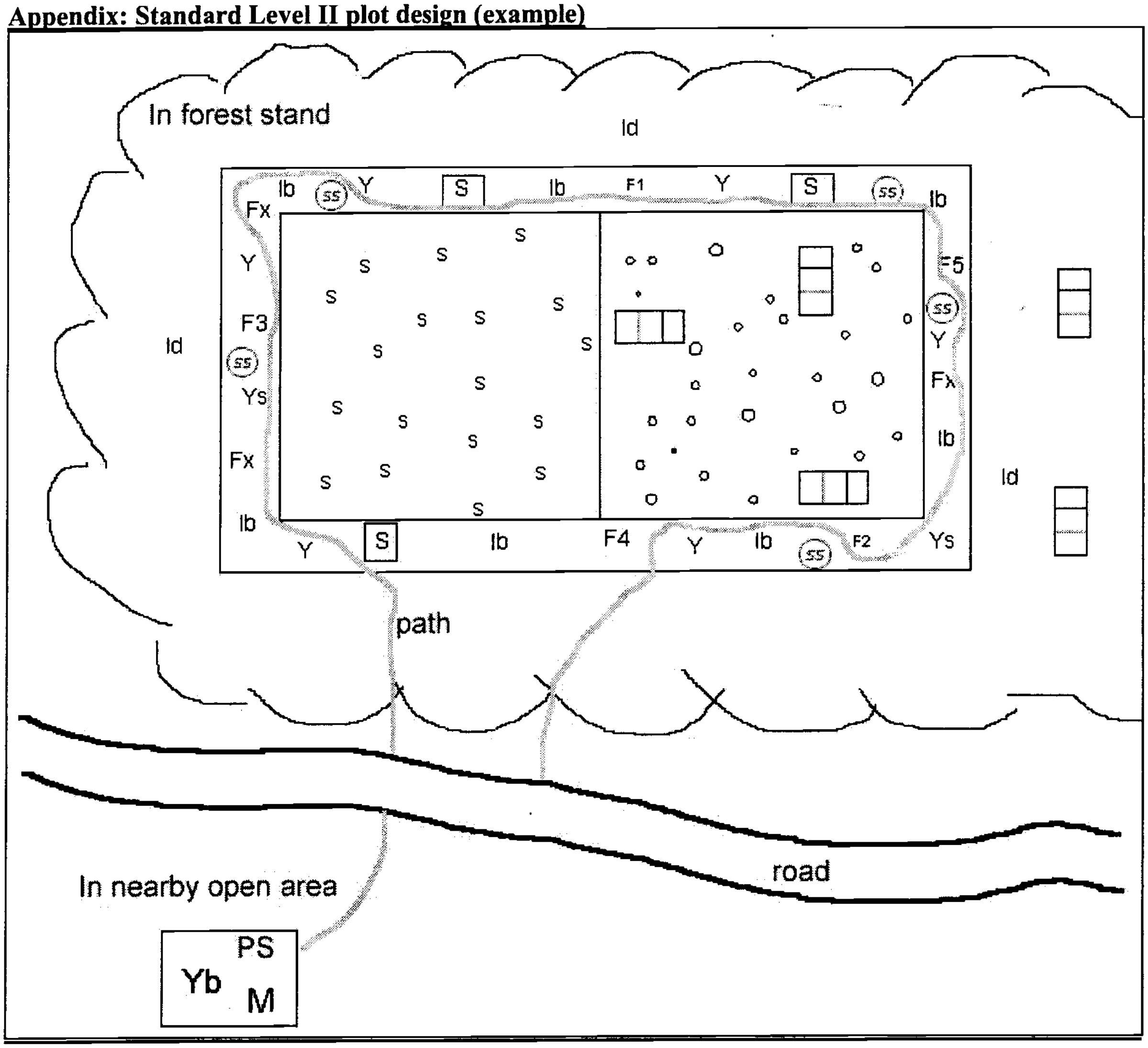
Litterfall

Throughfall collection systems will be located throughout the monitoring site and will be co-located with the lysimeters and near the deposition samplers. The physical samples will be collected on a monthly basis with the remaining continuously recorded data.

BENEFITS OF THE RESEARCH

The data collected at the Sierra Ancha Experimental Forest will contribute to a better understanding of the relationships between the condition of forest ecosystems and anthropogenic (in particular air pollution) as well as natural stress factors through intensive monitoring on a number of selected permanent observation plots and to study the development of important forest ecosystems. Further, the results will provide a deeper insight into the interactions between the various components of forest ecosystems by compiling available information from related studies, and in close co-operation with the ICP on modeling and mapping will contribute to the calculation of critical levels/loads and their exceedances in forest ecosystems. Ideally this will improve collaboration with other environmental monitoring programs as well and contribute to the monitoring activities to other aspects of relevance for forest policy at national and global level, such as effects of climate changes on forests, sustainable forest management and biodiversity in forests. Lastly, the network will provide policy-makers and the general public with relevant information.

Appendix: Standard Level II plot design (example)



Crown assessment
o Tree for crown assessment (yearly)

Soil (every 10 years)
s Location for soil sampling (minimal disturbance)
S Location for soil pit

SS Soil solution samplers

Deposition and ambient air quality
Y Throughfall collector
Ys Stemflow collector (in beech mandatory)
Yb Bulk or wet-only collector
PS Passive Samplers
(always located outside fence)

Foliar
Fx Tree x for foliar sampling (2-yearly)

Increment
o Trees for increment measurement DBH (5-yearly)
Ib Trees for increment measurement bores (once)
Id Trees for increment measurement disks (once)

Meteorology
M Meteorological equipment

Ground vegetation
? ? ? Ground vegetation sampling areas

A CONTRAST AMONG NATIONAL FOREST WATERSHED PROGRAMS: 1978 - 2008

Robert E. Lefevre[1]

Watershed management program on the Coronado National Forest has changed dramatically in the thirty years between 1978 and 2008. This paper presents the changes brought about by changes in national leadership, program emphasis, funding level, and technology. The Coronado National Forest is located in Southeastern Arizona and Southwestern New Mexico, in the Southwestern Region. The watershed management program on the Coronado National Forest has been influenced by four factors throughout the period of 1978 -2008: National Leadership; local Program Emphasis; Funding Level for the program; and Technology available. Each of these factors is addressed briefly below. The meaning of "National Leadership" has been identified by the Chief of the Forest Service in office at the time.

1978-1979: Chief John McGuire National Leadership

Chief McGuire was nearing the end of his term in office in 1978. The National Forest Management Act of 1976 was just beginning to be implemented. McGuire is quoted as saying "perhaps the greatest challenge facing forestry today is the calendar-namely the arrival of the 21st century.My question is, will American forestry be ready to meet the 21st century?" (http://www.foresthistory.org/, 2004).

Program Emphasis

A Supreme Court Decision shaped local program emphasis. The Mimbres Decision of 1978 took the Forest Service by surprise (Gillilan and Brown, 1997). The decision said that while the Multiple-Use Sustained-Yield Act of 1960 (Public Law 86-517) was intended to broaden the purposes for which national forests had previously been administered, Congress did not intend to reserve additional water in forests previously withdrawn under the 1897 Act. The effect of the decision was that all the Forests in New Mexico and Arizona had to research all water uses and determine if any needed to be certified through the respective State water codes. Over 2,000 water uses on the Coronado National Forest alone required certification. Fortunately, Arizona had laws in effect at the time that allowed for registration of existing uses. Nearly all of the hydrologists' time on the Forest was consumed by the research and registration of water rights during 1978 and 1979.

Funding Level

Budget not an issue. A staff of four Soil Scientists and two Hydrologists was adequately funded. Timber and range programs were well funded and drove most activity, while watershed funds provided for an aggressive watershed restoration program. The majority of all water uses were for range allotment administration, and range funds paid for the registration costs.

Technology

The entire Forest Service had one computer, located at the Fort Collins Computer Center. Land Management Planning efforts tried to use that computer by requiring the use of "FORPLAN" (U. S. Congress, Office of Technology Assessment, 1992). With nearly all National Forests competing for time, scheduling difficulties and computer time backlogs were common. The planning process dragged on for years.

1979-1987: Chief Max Peterson National Leadership

Chief Peterson took on the task of implementing the National Forest Management Act of 1976 from John McGuire. He was concerned about the potential for controversy and was quoted as saying "...the resources of these (National Forest) lands are wanted by a large number of diverse users who see them as critical to meeting their future needs. Many also see their own desired use as either exclusive of other potential users or at least incompatible with

[1]Coronado National Forest· U.S. Forest Service, Tucson, Arizona

them. In any language, that spells controversy" (http://www.foresthistory.org/ 2004).

Program Emphasis

Water rights issues continued, as water rights registrations were winding down, the Gila River Adjudication proceedings began. More filings were required. The budget drove other program components, first a large amount of erosion control and other watershed restoration work, then adding other assignments not directly related to watershed. A third hydrologist was added to the Coronado staff. The Forest Plan on the Coronado National Forest was completed in 1986, and the Forest set about trying to implement it. The Plan included standards for riparian areas and direction to determine how many Coronado National Forest riparian areas met those stands. It also called for at least 50 percent of all riparian areas to be in satisfactory condition by the end of the first 10-year period. No definitions for "satisfactory condition" were given, and the standards referred to "natural conditions" with no definition for what "natural" was. A Forest protocol for riparian area assessment was developed in 1984, based almost entirely on vegetation parameters even though the Plan had standards for channel morphology as well.

Funding Level

The 1980 budget came with money and targets for watershed restoration. Burchard Heede of the Rocky Mountain Research Station had published more than 80 articles on gully rehabilitation and soil erosion control (USDA Forest Service, Rocky Mountain Station, 1993, Stream Notes, 1993). His work was used to design erosion control projects. However, by 1987 budgets had become an issue for the watershed management program. The Coronado National Forest reduced staffing from three hydrologists and four soil scientists to one hydrologist and one soil scientist, then assigned other duties including forestry program management and special uses management to these individuals.

Technology

Computers became more available, but using them to design projects still required the Fort Collins Computer Center. By the end of 1986, almost all Forest Service employees had a Data General Computer on their desk. Electronic messages (e-mail) and cell phones began to play a role in everyday work.

1987-1993: Chief Dale Robertson National Leadership

In response to the arrival of controversy as predicted by Chief Peterson, Chief Robertson led efforts by the Forest Service to find new and creative ways to manage the national forests, especially by emphasizing non-commodity (non-timber) resources, new forestry, new perspectives, and ecosystem management. Chief Robertson is credited with coining the "caring for the land and serving people" slogan (http://www.foresthistory.org/ 2004)

Program Emphasis

The wildfire season during 1987 in the west was huge and widely spread, including Yellowstone National Park and multiple National Forests in California. Locally on the Coronado National Forest, a prescribed burn in the Chiricahua Mountains escaped and caused concern about future prescribed burning programs and effects on watershed components. Regional Forester Sotero Muniz called for better management of riparian areas, resulting in a regional level effort to develop a riparian area assessment and monitoring protocol. The national call for ecosystem management resulted in the range management program on the Coronado to come under intense scrutiny, especially with regard to how it affected riparian areas. The new Regional protocol for riparian area assessment called "Riparian Area Survey and Evaluation" (RASES) came out in 1989 and was pressed into service to respond to the demand for information and proposals to improve riparian areas that didn't measure up. It included channel morphology and soil parameters in addition to vegetation. The Coronado, along with the Tonto National Forest modified RASES to fit local situations. The initial response to the assessments was to fence cattle out of riparian areas, but criticism mounted, as it seemed to be contrary to the national direction for holistic ecosystem management. The upland watersheds began to suffer a threat in addition to grazing and wildfire as a bark beetle attack killed a large number of mature ponderosa pine trees.

Funding Level

Budgets began to become a serious concern as the timber and range programs lost their power, and the budget process did not include "ecosystem management" as a line item or target accomplishment. The solutions were not immediately apparent.

Technology

Computers, pagers, and cell phones became increasingly important to day-to-day operations. Typing pools, which traditionally had carried out most tasks involving the preparation and filing of documents, disappeared and all employees were expected to do their own document preparation on their computers. The time required not only to do these added tasks, but to get trained on the rapidly developing technology was becoming a greater fraction of all employees', not just watershed management personnel, work time.

1993-1996: Chief Jack Ward Thomas National Leadership

Chief Thomas supported the implementation of a new ecosystem management approach on the national forests and grasslands. He is quoted as saying "ecosystem management is not just a timber sale; it's putting the timber sale into a bigger picture, including the watersheds, wildlife, roads, and people's needs and values..." (http://www.foresthistory.org/ 2005).

Program Emphasis

Watersheds were often thought of as a starting point to define areas in which to accomplish "ecosystem management." Ecosystem management resulted in a need for more information about watershed conditions at a variety of scales. Most of the data needed to do assessments was not available, so searches for data began in earnest. The General Ecosystem Survey, completed at the Regional level for Arizona and New Mexico in 1990 as an oversight part of the terrestrial ecosystem survey which would provide detailed soil and vegetation information was looked to, as was the RASES information and Arizona Department of Environmental Quality Water Assessments. The Rescission Act of 1995 (Rescission Act of 1995 (Public Law 104-19 Section 504(a)) required range allotment permits to have an environmental analysis under the National Environmental Policy Act (NEPA) completed before they could be issued. This caused watershed assessments to be prioritized in favor of those allotments needing analysis first. Nearly all watershed program activities in 1996 were in response to range allotment NEPA.

An unprecedented event in 1994 occurred when a lightning ignited wildfire in the Chiricahua Mountains burned over 27,000 acres mostly in mixed conifer forest, affecting every watershed on the range. Rucker Lake, the popular recreation development in Rucker Canyon was completely filled with sediment following the fire, and was abandoned. (Lefevre and Neary, 1999). Several large forest fires occurred in the Rincon Mountains and Huachuca Mountains, requiring emergency burned area assessments.

Funding Level

Range program funding began to increase to respond to the NEPA analyses. Watershed program personnel were funded through this, as watershed line items declined.

Technology

In addition to more computer technology, all terrain vehicles were being added to our fleet. Improved mobility and access made the assessments somewhat more efficient, but training to keep up with new technology offset some of the benefits.

1996-2001: Chief Mike Dombeck National Leadership

Chief Dombeck focused his efforts on promoting partnerships, collaborative stewardship, accountability, and financial health. An avid fisherman, he considered watershed management an important task: "Watershed maintenance and restoration are the oldest and highest callings of the Forest Service" (http://www.foresthistory.org/2004).

Program Emphasis

In spite of the call for watershed programs to take their place at the center of National Forest management, an increased emphasis on fuel management arose in response to large wildfires both locally and on the national scene. This in turn resulted in a need to assess watershed impacts from more mechanical vegetation treatments and prescribed burns in addition to the continued demand for analysis of range allotments. Endangered aquatic species on the Coronado National Forest began to take center stage as drought caused habitats to shrink. The last remaining populations of native frogs and fishes were frequently found in waters found to harbor introduced species and disease in addition to being located in range allotments. The demand for data and analysis to develop proposed actions to save these habitats became intense. The RASES and newly developed "Soil Quality Assessment" (FSH 2509.18, 1999) were stretched to their limits in attempts to help decision makers.

Funding Level

Funding levels stayed flat in the face of rising costs of doing business. Local watershed program personnel, already assigned other programs including forestry and special uses, diversified by getting training to support wildfire suppression actions.

Technology

Geographic Information Systems (GIS) began to become the accepted way to conduct and display nearly all analyses. The programs required training and space to run, and computers began to fail as more and more demands were placed on them. Bigger, more powerful computers began to replace the original Data General models, and by 1997 many documents created on the Data General computers were no longer available. Hard copies became invaluable as it was discovered that we could no longer read or print documents created as recently as 1994.

2001-2007: Chief Dale Bosworth National Leadership

Chief Bosworth continued the recent trend in national direction to build relationships and partnerships. He tried to get more traditional authority to the District Rangers by saying the "decisions need to be made at the lowest level that they can. We need to build better relationships with local communities and with states, tribes, and others" (http://www.foresthistory.org/, 2007).

Program Emphasis

As national emphasis pointed toward more local relationships, the Coronado was forced into intense local situations that required relationships with the counties and communities. Wildfires in the Santa Catalina, Pinaleño, Tumacacori, Huachuca, and Santa Rita Mountains required detailed burned area assessments. Large burned area emergency response (BAER) teams were formed, absorbing large amounts of watershed personnel time, and that after extended tours on suppression assignments by the same individuals. Implementation of the BAER projects, followed by long term restoration needs and project implementation resulted in the watershed program being dominated by wildfires. The unexpected number of large fires nationally resulted in a renewed call for action to manage forests. The Healthy Forest Restoration Act (HFRA) (PL 108-148) of 2003 called for specific action that required some watershed assessment. The Rescission Act schedule also required continued assessment to complete range allotment analyses.

Funding Level

The HFRA projects and range management NEPA provided funding, as did a Southwestern Region initiative to gather data for potential instream flow water rights. New hydrologist and silviculturist positions were added to the Coronado organization to assist in these programs.

Technology

Digital cameras began to be more common, as did global positioning system (GPS) units. Both of these new technologies could be linked to the GIS projects, creating complex data storage situations requiring even more powerful computers.

2007-present: Chief Abigail Kimbell National Leadership

Chief Kimbell has started her term continuing the emphasis on ecosystem management. She is quoted as saying "we have to manage for the health of the whole landscape- for clean water, for wildlife habitat, for healthy vegetation, for recreation" (http://www.foresthistory.org/ 2008).

Program Emphasis

Forest restoration with an emphasis on fuels management and range allotment NEPA continue to demand much of the watershed program attention. Burned area restoration and response to situations within the burned areas also commands attention. Forest Plan Revision is requiring a new look at water resources. The Gila River adjudication and other continuing water rights issues (refer to 1978 discussion) are still in progress, thirty years after they began, with no end in sight.

Funding Level

Budget levels remain static. Watershed personnel continue to respond to projects and programs, and are funded by them. In addition to forest restoration and range management, new mineral development is starting to command a lot of attention and time.

Technology

All the computer hardware purchased and maintained over the last decade is slowly being upgraded and replaced. Software support has been centralized.

CONCLUSIONS

Thirty years of change, especially in national leadership and technology, have had little effect on local programs for the Coronado National Forest. Water rights and riparian areas continue to dominate the program. Plan revision offers the opportunity to make riparian area assessment and management more meaningful, but how to accomplish it remains difficult. As population and demands on the Forest increase while drought threatens day-to-day supply, water use and rights remain important topics.

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SOUTH-TO-NORTH WATER DIVERSION PROJECT IN CHINA

Hui Chen[1] and Peter F. Ffolliott[1]

The South-to-North Water Diversion Project in China is the largest water project of its kind ever undertaken in the world. It was proposed in 1952 and the main construction was started in 2002 after 50 years of baseline inventorying and study. The project is expected to be completed in 2050 with a total investment of approximately 486 billion yuans (1 dollar = 8 yuans in 2002). The South-to-North Water Diversion Project will not only relieve the severe water shortage in northern China, but, more importantly, it will efficiently manage water resources by establishing a strategic water distribution and security network for the Yangtze River, Yellow River, Huai River, and Hai River. The project consists of three routes - the Western Route, the Middle Route, and the Eastern Route - diverting water from upstream, mid-stream, and downstream of the Yangtze River, respectively. The total water to be transferred in the project is expected to be nearly 44.8 billion m^3 annually by 2050, with 17.0 billion m^3, 13.0 billion m^3, and 14.8 billion m^3 of water transferred by the Western Route, the Middle Route, and the Eastern Route, respectively.

This paper on the South-to-North Project consists of a background explanation of why China needs this water project; a section on how the Three Route Project will be constructed; the expected social, economical, and ecology benefits; and existing and potential future impacts of the project on ecology and the environment.

BACKGROUND

The large population in China (about 1.3 billion people in 2002) is unevenly distributed, with a high density of people in eastern China and a low density in western China. The spatial distribution of water resource is also uneven, with higher resources in the south and east than in the north and west. The current distribution of water resources is not compatible with the distribution of the population and agricultural, industrial, and social development. The level of water shortage in China in 2000, representing the water resource, social and economical development, water supply, water demand, water shortage and water quality, indicates sufficient water resources in southern China but a deficiency of water resources in northern China (Figure 1). The shortage of water resources in northern China will only get worse with the anticipated social and economical development. The South to North Water Diversion Project is expected to relieve this problem.

THREE ROUTE PROJECT

Since beginning to consider the feasibility of implementing the South-to-North Water Diversion Project in early 1950s, more than 150 alternative layouts for the project had been proposed, with the Three Route Project ultimately chosen for implementation. The Three Route Project (Figure 2), including the Western Route Project, the Middle Route Project, and the Eastern Route Project, will divert water from upstream, mid-stream, and downstream of the Yangtze River, respectively, to connect the four major rivers - the Yangtze River, Yellow River, Huai River, and Hai River - into a national water resource network.

Eastern Route Project

Construction of the Eastern Route Project started in December 2002 and is planned for completion in 2016, with a total investment of 65 billion yuans. The Eastern Route Project will divert water from a downstream branch of the Yangtze River to the eastern Huang-Huai-Hai Plain, with the termination in the Tianjin Municipality via the existing Beijing-Hangzhou Grand Canal, which is the oldest and longest canal in the world. The Eastern Route Project is expected to relieve water shortages in the Tianjin Municipality, the Heilonggang Yundong regions in the Hebei

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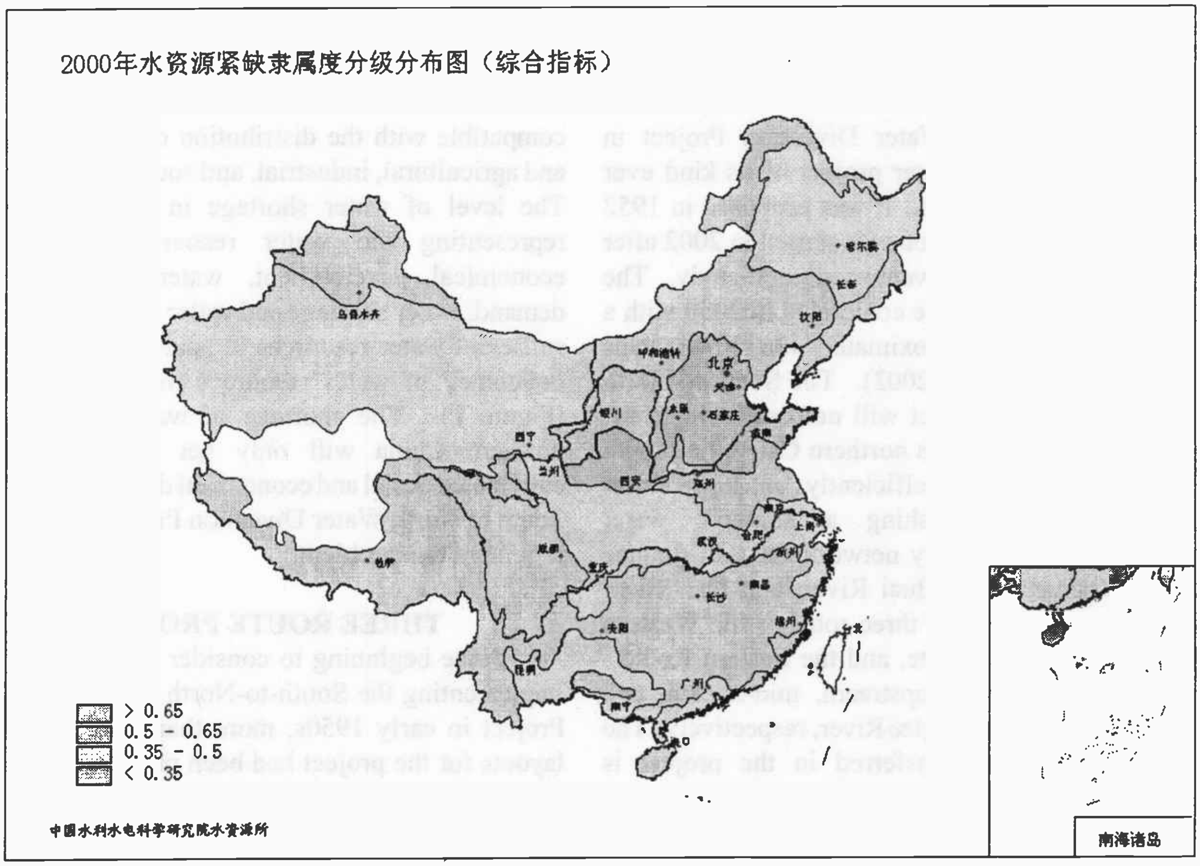

Figure 1. Distribution of the water shortage index in China in 2000. (Source: (http://sdinfo.chinawater.net.cn/waterresources/ww007.jpg))

province, and the north and southwest part of Jiaodong Peninsula of Shandong Province. As already stated, it will divert water from the Yangtze River, which normally has mean annual water flow of 960 billion m^3 entering the Eastern Sea and more than 760 billion m^3 of water flow in extremely dry years. The length of the completed water-course will be about 1,560 km from the Yangtze River to the Tianjin Municipality. The Eastern Route Project involves establishing 13 pumping stations south of the Yellow River where the water will then flow to the Tianjin Municipality by gravity. The Eastern Route Project also involves the construction of a nearly 9 km tunnel beneath Yellow River. When completed, the Eastern Route Project is expected to divert approximately 14.8 billion m^3 of water per year.

Middle Route Project

The Middle Route Project was started in December 2003 and its completion is expected in 2050, with a total investment of 117 billion yuans. The Middle Route Project will divert water from the Danjiangkou Reservoir on Han River to the Beijing Municipality in the short-run. In the long-run, the Middle Route Project will divert water from the Three Gorges Reservoir or downstream of the dam on the main branch of the Yangtze River to the Beijing Municipality, the Tianjing Municipality, and the provinces of Hebei, Henan, and Hubei. The main advantage of this project is that water will flow by the forces of gravity. Two key components of the construction effort for this project are heightening the Danjiangkou Reservoir dam from 97 to 170 m and building two tunnels of 8.5 m in internal

Figure 2. Layout of the Three Route Project of South-to-North Water Diversion. (Source: (http://www.water-technology.net/projects/south_north/south_north1.html))

diameter and about 7 km long with a planned flow capacity of 500 m^3/s. After the completion of the Danjiangkou Reservoir, the mean annually transferred water will be increased from 12.0 to 14.0 billion m^3 in normal years and 6.2 billion m^3 in dry years. Another benefit of Danjiangkou Dam Extension Project is that it will increase the level of flood control in the middle and lower Han River and enhance the safety of Wuhan City and the plain to the north of the Han River. The diversion route of the Middle Route Project will be about 1,274 km in length, starting at the head of the Taocha canal and terminating at the Yuyuan Pool in Beijing. The Middle Route Project will supply water to Beijing for the 2008 Olympic Games. The transferred water is temporarily from reservoirs in the Hebei province, with an annul flow rate of 0.4 billion m^3.

Western Route Project

The Western Route Project is expected to start in 2010, with the investment of 300 billion yuans, an amount accounting for 60% of total investment for the South-to-North Water Diversion Project. The Western Route Project is expected to relieve the water shortage in the north and northwest of China. It will divert water from the upper reach of the Yangtze River to Yellow River. The Western Route Project is planned to transfer 20 billion m^3 of water annually from three tributaries of the Yangtze River, including 10 billion m3 from the Tongtian River in the upper reach of Yangtze River, 5 billion m^3 from the Yalong River, and 5 billion m^3 from the Dadu River. Two main parts of the construction effort for the West Route Project are building a dam with a height more than 200 m and digging a tunnel through the Bayangela Mountain with the length of more than 100 km. This project will necessitate overcoming major engineering and climatic challenges because it is situated on the Qinghai-Tibet Plateau where the elevation is between 3,000 and 5,000 m and is characterized by complicated geological structures, extremely low temperatures, and frequent and severe earthquakes up to 8 to 9 degrees on Richter scale in some areas.

BENEFITS

The South-to-North Water Diversion Project will eventually divert about 38 to 48 billion m^3 of water per year. It is expected to have important social, economic and environmental benefits for the

Huang-Huai-Hai District by alleviating the existing water shortage, promoting socio-economic development, and improving living conditions for the nearly 300 million residents of urban and rural areas. Some of these benefits are discussed below.

Social Benefits

The South-to-North Water Diversion Project will have social benefits to the water district. For example, Beijing, the capital of China, is the nation's center of political, cultural, financial and diplomatic activities. Tianjin is the largest industrial base in northern China and, additionally, an important trade port. The western and northwest region is the country's base of energy resources, raw materials, and heavy chemical industries. The South-to-North Project will ease the competition for water between geographic regions and between the agricultural and industrial sectors. It will also reduce or relieve regional health problems such as fluoride bone and thyroid problems due to drinking contaminated deep groundwater.

Economical Benefits

It is planned that 40% of 17 billion m^3 of water transferred by the Eastern Route Project will be allocated to urban and industrial uses and 60% to rural and agricultural uses. About 65% of 13 billion m^3 of water transferred by the Middle Route Project will help to satisfy urban and industrial needs and 35% will be made available to rural and agricultural uses. One-half of the 14.8 billion m^3 of water to be transferred by the Western Route Project will go to urban and industrial uses and 50% to the rural and agricultural sectors. Based on recognized criteria for agricultural and industrial outputs and the current price level, the average annual economic benefit from the South-to-North Diversion Project will be approximately 60 to 80 billion yuans. Importantly, it is also expected that the financial inputs and outputs for this project will come into balance in less than 10 years.

Ecological and Environmental Benefits

The transferred water will increase the supply of water to people and the industrial sector, improve sanitation, and enhance the vegetative cover in urban areas. The project will also increase the water supply to agriculture and livestock purposes, adjust the agricultural crop components to improve efficiency, and increase the overall level of agricultural production. The diverted clean water will replace sewage water for agricultural irrigation purposes and, in doing so, reduce pollution of agricultural lands and improve the quality of agricultural production. The increasing availability of clean water will also reduce excessive extraction of groundwater and, as a consequence, alleviate the problem of declining aquifers. By reasonable water distribution, it will be possible to recharge dry wetlands, creeks, and streams, which will likely increase the ability of self-dilution and self-cleaning of water resources and promote the development of aquatic biological resources.

ECOLOGICAL AND ENVIRONMENTAL IMPACTS

As the largest water project in the world, the South-to-North Water Diversion Project certainly has existing problems and could have problems in the future such as financial, technical, and mechanical problems and, as discussed here, ecological and environmental problems. Poor water quality for the Eastern Route Project, severe soil erosion for the Middle Route Project, and feasibility and reliability for Western Route Project are among the most crucial of these possible problems.

Eastern Route Transfer Project

The main problem with the Eastern Route Project is the poor quality in the water output district. The project uses the Beijing-Hangzhou Grand Canal and other natural rivers and lakes as its watercourse. Main sources of pollution at this time are the point-discharges of sewage pollution from living and industry; surface discharges of water containing chemical fertilizers and pesticides that are applied widely on agricultural lands around the Huai River, the Yellow River, and the Hai River; the high sediment concentrations resulting from the movement of large sediment deposits within the transferred water; and pollution resulting from the heavy traffic of shipping that takes place on the Beijing-Hangzhou Grand Canal. Water pollution control and its treatment will be the first step to insuring that the diverted water meets established quality standards. Planned pollution control projects include building urban sewage treatment system, industrial sewer diversion, adjustment of the industrial structure, and comprehensive management of industrial and watershed treatment.

Middle Route Project

The major problem for this project is that the ecological environment is deteriorating. The mountain areas with steep slopes and a high level of ecosystem fragmentation are prone to severe soil erosion. Another concern for the Middle Route Project is that the quality of water is getting progressively worse due to the increasing discharges of living and industrial wastewater into the Han River and Dan River. Treatment of soil erosion and wastewater, therefore, will be the highest priority in diverting clear water to the north.

Western Route Project

The Western Route Project will divert water from the upstream of the Yangtze River to the Yellow River. It is located on the eastern Qinghai-Tibet Plateau, with elevations of 3,000 to 5,000 m. There is inherently a high diversity of geomorphology and rich natural resources in the project area. Fortunately, the change of water flow should not have significantly adverse impacts on the biological stock of the region that relies mainly on precipitation inputs for survival. Although construction on the project will begin in 2010, its feasibility and reliability is still debated, since it is both an inter-basin water transfer project and a large-scale ecological and environmental project. Current arguments are centered around the main issues that building the high dam could trigger the occurrence of higher degrees of earthquakes in this area; constructing a tunnel of a 100 km length and a dam with a height of 200 m is a technical and mechanical challenge considering the geomorphology characteristics in this mountain area; and a recognition that the natural ecological system is fragile, and, as a consequence, the ability of the ecosystem to sustain itself is unknown after the massive of grassland and agricultural lands are destroyed. And finally, the Tibetans living in this area of the project worship at highly regarded temples; the high mountains of the region have special meaning to the people; and the natural waters of the area have a great value. Of particular note, relocation and rebuilding of the temples is another large problem.

CONCLUDING COMMENT

Taking 50 years from conception to commencement, the South-to-North Water Diversion Project is expected to require another 50 years to complete its construction. After it is completed in 2050, at a total investment of 486 billion yuans, this large project will eventually transfer 44.8 billion m^3 of critically needed water per year to benefit the growing population centers of the drier regions of northern China. It is indeed at unique undertaking.

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TRANSPIRATION OF OAK TREES IN THE OAK SAVANNAS OF THE SOUTHWESTERN BORDERLANDS REGION

Peter F. Ffolliott,[1] Cody L. Stropki,[1] Aaron T. Kauffman,[1] and Gerald J. Gottfried[2]

Transpiration of oak trees on the Cascabel watersheds in the savannas on the eastern slope of the Peloncillo Mountains in southwestern New Mexico has been estimated by the sap-flow method. Transpiration represents the largest loss of gross precipitation falling on a watershed in approximations of water budgets for the more densely stocked oak woodlands of the Southwestern Borderlands region (Ffolliott 2000, 2004, Shipek et al. 2004). Knowledge of transpiration is also important, therefore, in developing a general water budget for this more open ecosystem. An initial estimate of the transpiration of oak trees in the oak savannas of the Southwestern Borderlands region is presented in this paper.

STUDY AREA

Twelve small watersheds have been instrumented and sampled in the Peloncillo Mountains to study the effects of cool season (November-April) and warm-season (May-October) prescribed burning on the multiple resources of oak savannas in the Southwestern Borderlands. The watersheds are located near the Cascabel Ranch in the eastern part of the Coronado National Forest near the Animas Valley of southwestern New Mexico. The watersheds are 5,380 to 5,590 feet in elevation. The weather station at the Cascabel Ranch headquarters indicates that annual precipitation in the vicinity of the watersheds averages 21.8 " 1.2 inches, with more than one-half falling in the summer monsoon from late June through early September. However, a prolonged drought impacted the Southwestern Borderlands region from the middle 1990s to the present time. Annual precipitation during this drought period has averaged 14.9 inches. Geological, edaphic, hydrologic, and vegetative characteristics of the Cascabel Watersheds have been described by Gottfried et al. (2007) and, therefore, are not included in this paper.

STUDY METHODS

Instantaneous transpiration of 16 Emory oak (*Quercus emoryi*) trees, the dominant oak species on the Cascabel Watersheds, was measured with a sap-flow meter (Swanson and Whitfield 1981, Swanson 1994, Schaeffer et al. 2000) in the late spring, summer, and early fall of 2004. The measured trees were located on two transects oriented perpendicular to the main stream channel on each of two Cascabel Watersheds, specifically, Watersheds E and I (Gottfried et al. 2007). Two of the trees were situated on the southerly aspect and two trees on the northerly aspect of each transect for a total of 16 measured trees. The trees ranged in drc (diameter root collar) from 6 to 14 inches. Parenthetically, errors of 5 to 15 percent are commonly associated with the measurement of instantaneous transpiration of individual plants with a sap-flow meter (Shuttleworth 2008).

The instantaneous measurements of transpiration of the Emory oak trees measured were transformed into approximations of daily transpiration by applying the equations of Barret et al. (1995) and Schaeffer et al. (2000). The resulting estimates of daily transpiration were considered to be a proxy for other oak species on the Cascabel Watersheds. Emory oak represented 75.5 percent of the oak trees on these watersheds, with Arizona white oak (*Q. arizonica*) and Toumey oak (*Q. toumeyi*) comprising 14.3 and 10.2 percent, respectively.

Earlier studies of transpiration in the oak woodlands on the southern slope of the Huachuca Mountains indicated that values of daily transpiration of oak trees cycled through time on an annual basis, ranged from relatively high values of transpiration following the summer monsoons and winter rains to intervening low values (Ffolliott and Gottfried 1999). It was hypothesized by the authors of this paper that this cycle of annual transpiration

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rates also applies in the oak savannas. To test this hypothesis, the estimates of daily transpiration rates obtained for the oak trees on the Cascabel Watersheds were plotted on a figure representing this cycle in the oak woodlands of the Huachuca Mountains (Figure 1).

and their respective drc values was coupled with the Cascabel stand table, which presented tree frequency per acre, to obtain the estimate of annual transpiration in area-inches. Information on the frequency of oak trees was obtained from an earlier inventory of the tree overstories on the watersheds (Gottfried et al. 2007).

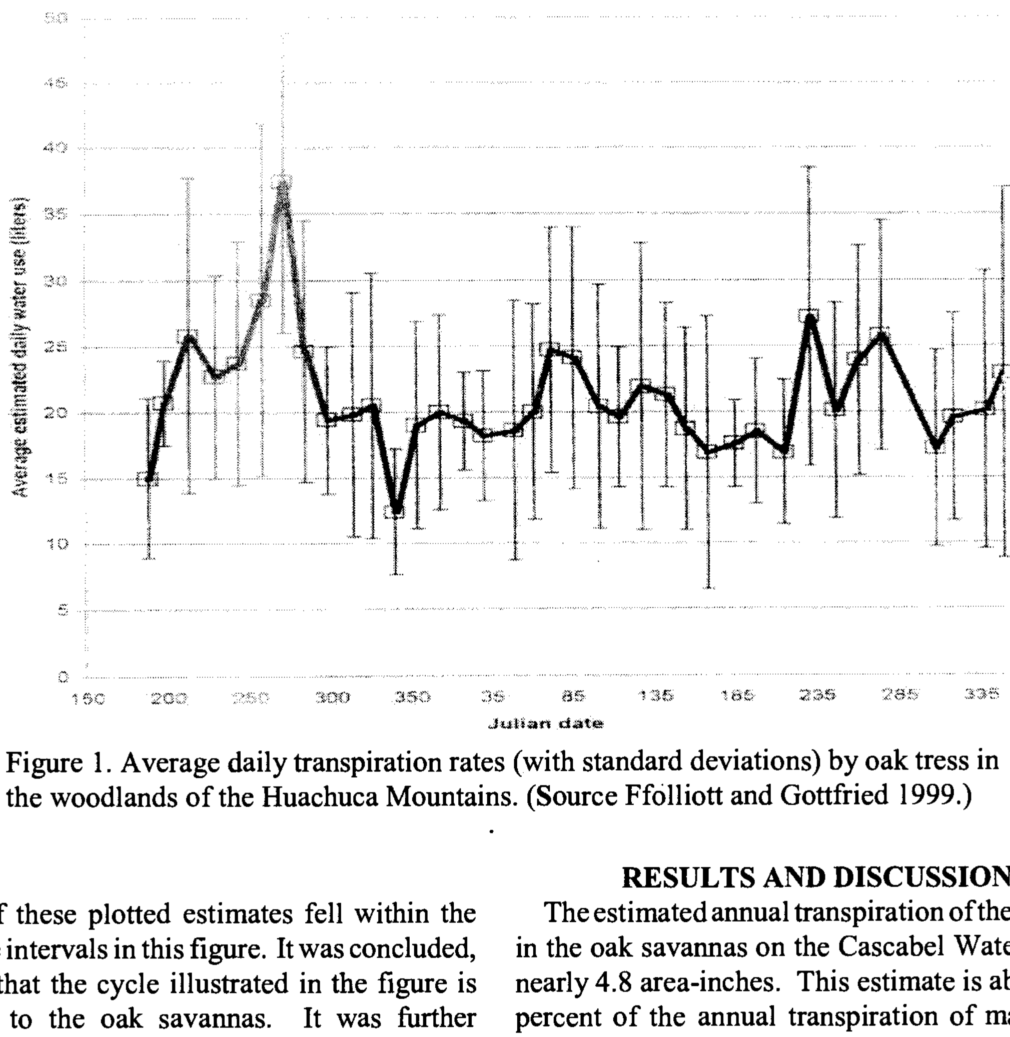

Figure 1. Average daily transpiration rates (with standard deviations) by oak tress in the woodlands of the Huachuca Mountains. (Source Ffolliott and Gottfried 1999.)

All of these plotted estimates fell within the confidence intervals in this figure. It was concluded, therefore, that the cycle illustrated in the figure is applicable to the oak savannas. It was further concluded that the relationship between annual transpiration and the drc of oak trees in the oak woodlands on the Huachuca Mountains (Figure 2) is also representative of the oak savannas on the Cascabel Watersheds. Relationship illustrated in figure 2 became a basis for obtaining an estimate of annual transpiration of the oak trees in the oak savannas in terms of area-inches. The relationship between estimated annual transpiration of oak trees

RESULTS AND DISCUSSION

The estimated annual transpiration of the oak trees in the oak savannas on the Cascabel Watersheds is nearly 4.8 area-inches. This estimate is about 60 percent of the annual transpiration of mature oak trees (60 years and older) in a stand on the Huachuca Mountains (Ffolliott and Gottfried 1999, Ffolliott et al. 2003). The last (known) harvest in the Huachuca stand selectively removed larger oak trees for mining timbers in 1895, and, therefore, the stand appeared to be largely representative of structure of uncut stands in the region when sap-flow measurements to estimate transpiration were made in 1997-1998. The lower value for annual transpiration in the oak

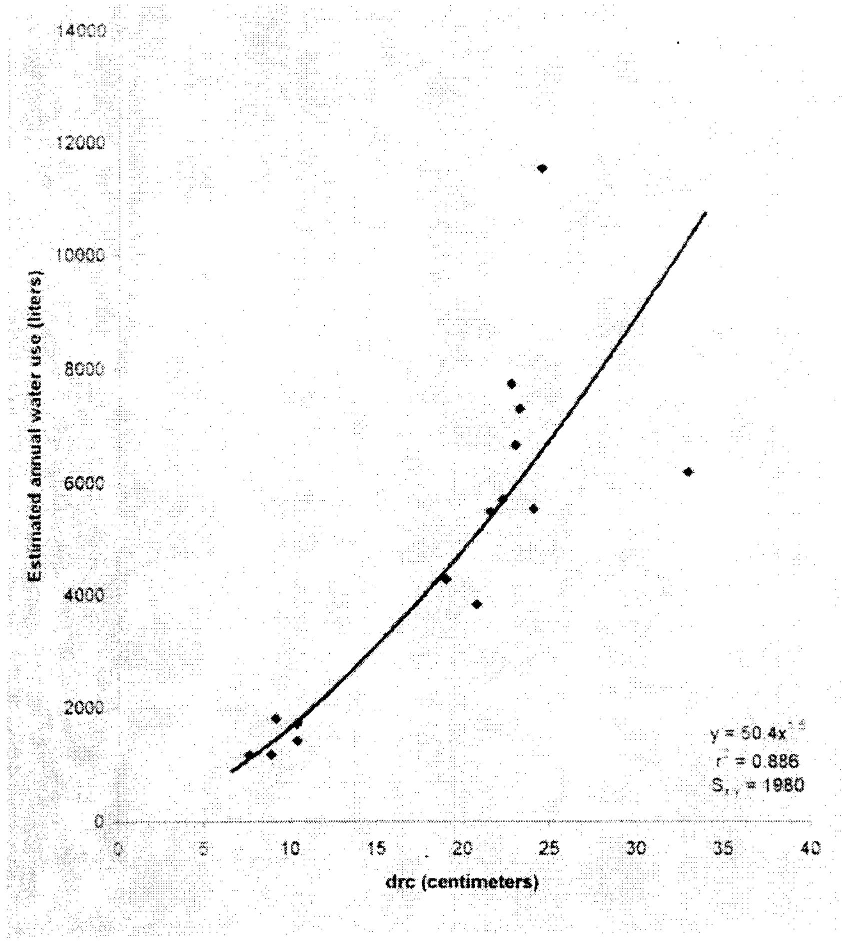

Figure 2. Relationship between annual transpiration and drc (diameter root collar) of oak trees in the woodlands of the Huachuca Mountains.

savannas is attributed largely to the smaller number of oak trees in the oak savannas compared to the oak woodlands. The average number of oak trees on theCascabel Watershed is 42.6 stems per acre (Ffolliott and Gottfried 2005), while that in the sampled stand in the oak woodlands on the Huachuca Mountains was 183.1 stems per acre (Ffolliott et al. 2003).

Annual transpiration of oak trees can also be expressed as a percent of annual precipitation. An arbitrary annual precipitation value of 450 millimeters (about 17.7 inches) had been selected earlier as a basis to present this percentage for varying stand conditions and silvicultural treatments in the oak woodlands on the Huachuca Mountains in earlier studies (see Table 1 in Ffolliott 2004). This precipitation value is within a range of the variable annual precipitation amounts occurring in the oak ecosystems in the region. Accepting this value as a basis for developing a similar expression for the transpiration of oak trees in the oak savannas indicated that the annual transpiration of the oak trees on the Cascabel Watersheds is approximately 30 percent of annual precipitation. Comparisons of this value with the relationships obtained for the different stand conditions and silvicultural treatments in the oak woodlands are shown in figure 3.

The most valid comparison presented in figure 3 is that between the annual transpiration of oak trees in the oak savannas on the Cascabel Watersheds and the oak trees in the uncut stand of mature oak trees in the oak woodlands of the Huachuca Mountains (Ffolliott and Gottfried 1999, Ffolliott et al. 2003). These two sites are generally similar in the past and present land-use practices imposed on them. The

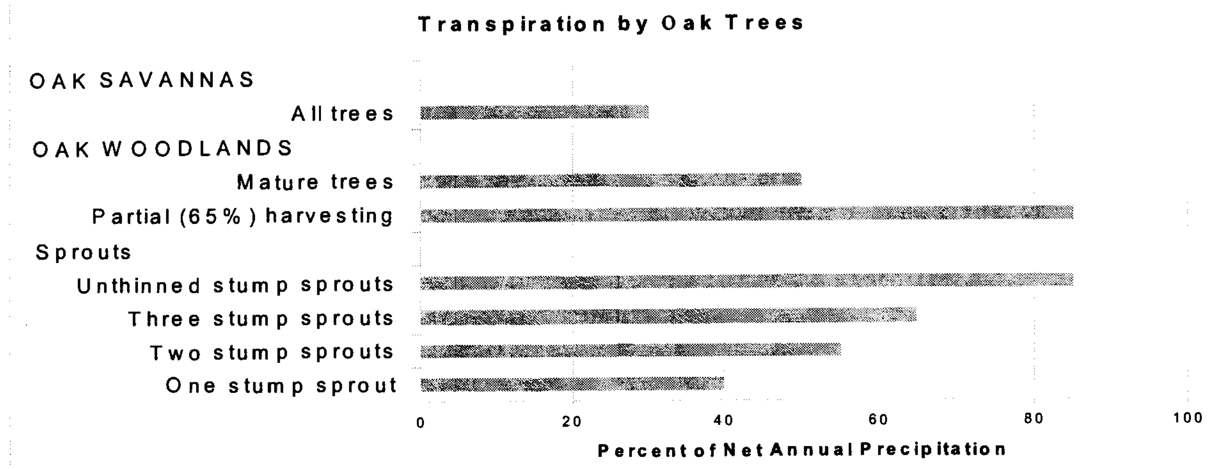

Figure 3. Annual transpiration of oak trees in the oak savannas as a percent of the (arbitrarily) selected annual precipitation value of 450 millimeters (about 17.7 inches) and varying stand conditions and silvicultural treatments in the oak woodlands on the Huachuca Mountains. Percentages for the oak woodlands were obtained from the studies reported by Ffolliott and Gottfried (1999), Ffolliott et al. (2003), Ffolliott (2004), and Shipek et al. (2004).

other comparisons presented in the figure are offered for information only.

The partial firewood harvest removed 65 percent of the mature oak trees in the oak woodlands of the Huachuca Mountains in 1981. Transpiration of the residual mature oak trees and the resulting stump sprouts (combined) was measured with a sap flow meter in 1997-1998 approximately 16 years after the firewood harvest. One factor contributing to the greater estimated transpiration in this stand was the large number of stump sprouts (Ffolliott and Gottfried 1999). Although the number of residual mature oak trees in this stand was (statistically) similar to the number of trees in the uncut stand of mature oak trees, there was a (very) large number of post-harvest stump sprouts. Even though the estimated transpiration of an individual stump sprout was comparatively small, the large number of sprouts in the stand translated into the greater annual transpiration value (Figure 3). There were 370.2 stump sprouts per acre in the stand when the measurements of transpiration were made (Ffolliott and Gottfried, Ffolliott et al. 2003). This number of sprouts was considerably larger than that normally found in the oak woodlands (Touchan 1988).

The stump-sprouts on rootstocks of some of the trees in the harvested stand were thinned to one, two, and three of the dominant sprouts in 1984 to evaluate the effects of coppice thinning treatments on residual growth and volume (Bennett 1988, Touchan and Ffolliott 1999, Farah et al. 2003). Transpiration was measured with a sap-flow meter on 16 of these rootstocks representing each of these thinning treatments and an unthinned control in 2000, approximately 20 years following the firewood harvest (Shipek et al. 2004). Expressions of these annual transpiration values as a percent of the annual precipitation amount selected in the earlier studies are also shown in figure 3. Note that the transpiration of stump sprouts on the unthinned root-stocks is similar to the transpiration of stump sprouts in the partially harvested site, because of the overwhelming dominance of stump sprouts.

CONCLUSIONS

Annual transpiration of oak trees in the oak savannas is about 60 percent of the annual transpiration in a stand of mature oak trees in the oak woodlands. The lower value estimated for the oak savannas was likely due to differences in the densities of oak trees in the two ecosystems. The number of oak trees in the oak savannas is less than that in the oak woodlands. Further study is necessary, however, to verify or refine this initial estimate. Also, other tree species including alligator juniper, border pinyon, and the tree-form of mesquite are often present in the oak savannas, and, therefore, an estimate of the transpiration for these trees species is required to obtain a comprehensive estimate of transpiration in this ecosystem.

Knowledge of the transpiration by herbaceous plants on the Cascabel Watersheds would strengthen our understanding of water use by most components of the vegetative community. These data combined with existing measurements of precipitation and streamflow would then facilitate more accurate estimates of the water balance of the Southwestern Borderlands Region.

ACKNOWLEDGMENT

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HOW USEFUL IS LiDAR IN ESTABLISHING A STREAM GAUGING NETWORK IN A TROPICAL EXPERIMENTAL FOREST

Boris Poff,[1] Daniel G. Neary,[1] and Gregory P. Asner[2]

In the late summer of 2007 the Institute for Pacific Islands Forestry (IPIF), which is part of the US Forest Service Pacific Southwestern Research Station, asked the USFS Rocky Mountain Research Station's (RMRS) Air, Water and Aquatic Program's (AWA) Southwest Watershed Science Team for assistance in the establishing baseline data in the initial phase of a long term research project in the newly established Hawaiian Experimental Forest. RMRS and its predecessors have a history of the long standing watershed related research in the southwestern United States which was established experimental watersheds on volcanic rock over 50 years ago. Both systems, in Hawaii and Arizona, have mostly washes that have flashy precipitation events driven flows. Funding availability, personnel shortages and other ongoing collaborative projects between experimental forests of the research branches of the U.S. Forest Service facilitated the joint effort in this project.

STUDY SITE

The 12,343-acre Laupahoehoe Unit of the Hawaii Experimental Tropical Forest (HETF) is located in North Hilo on the Isle of Hawaii and was formally established on state land on March 23, 2007.It is one of two experimental forests in the HETF network (Figure 1).

Located upslope of former sugarcane lands, the site also contains timber plantations, degraded pastures and numerous streams. Its location and size make it an ideal global location for global climate change research studies of native forest restoration, invasive species control, and watershed management. The Laupahoehoe unit contains five streams, of which only two are perennial and contain aquatic organisms.

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Three streams have cut their stream beds through 65,000 year old rock formations, while the other channels exist on newer bedrock, which formed between 4,000 and 65,000 years ago. All channels are located in Akaka soils generic class, with the exception of the Kaawalii stream, which is located on Honokaa soils.

RESEARCH NEEDS

None of the stream channels in the HETF had previously been surveyed. Since its recent designation as an experimental forest, it became prudent to properly inventory, classify and survey the streams channels in the HETF. These activities are also necessary to select possible locations for stream gauging stations along those channels. While certain criteria for a stream gauge location can be evaluated using a GIS, such as proximity to roads, forest boundaries etc. other criteria, such as channel morphology still needs to be evaluated in the field. The first stream selected to be surveyed was the Kaawalii Stream in the Wet Forest vegetation zone of the HETF. This is one of five streams on Laupahoehoe Unit and is the number one priority for future research efforts, mostly due to its accessibility and proximity to one of the few roads in the HETF.

The first 2 km reach of the Kaawalii Stream fall within the Experimental Forest. The objective of this study is to complete a Kaawalii Stream baseline geomorphic survey and add one experimental gauged watershed to the EF. Gathered data will be used for future studies of the effects of climate change on hydrology channel substrates, aquatic organisms, and coarse woody debris. Required work consists of the establishment of cross-section, GPS monumenting, photo documentation, channel classification, geologic substrate, and pebble counts. This includes running level surveys of the cross-sections to provide a baseline of channel conditions, and ground-truth data for the LiDAR survey, establishing of coarse woody debris status in the streams and conducting baseline aquatic organism surveys. Location of the Laupahoehoe

Experimental Forest in the Hawaii Experimental Tropical Forest as shown in figure 1.

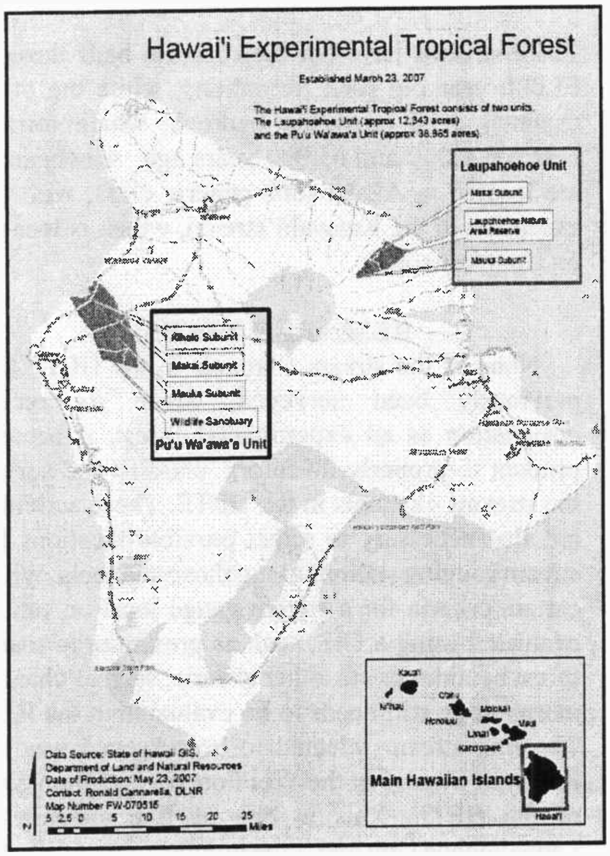

Figure 1. Tthe Laupahoehoe Experimental Forest in the Hawaii Experimental Tropical Forest.

METHODS

The methods used in this study consist of a LiDAR mission flown over the HETF and field work conducted by a survey crew in the Kaawalii stream channel. Both projects were carried out in 2007.

LiDAR

In the summer of 2007, the Carnegie Airborne Observatory (CAO) LiDAR was flown at 2000 m a.g.l., at 50 khz pulse repetition rate, which resulted in 1.0 m spacing between laser spot centers. The resolution of each laser spot was 1.2 m. Maximum scan angle was limited to 18 degrees off-nadir.

Field Methods

The lower 900 m of the 2 km reach of the Kaawalii Stream within the HETF were surveyed during the last week of September 2007. Cross-sections were established at randomly pre-selected locations on successive 100 m segments of the stream. The cross-sections were permanently monumented, photo-documented, located with GPS coordinates, channel-typed using the Rosgen method, and measured for substrate composition using the pebble-count method. These cross-sections constitute ground-truth data for a LiDAR database being constructed for the HETF.

DISCUSSION OF METHOD

While the CAO LiDAR was intended to specialize in vegetation, it can also identify hidden geomorphologic features in the landscape. The CAO scan indicates a series of depressions-water catchments and channels on the forest floor. These features have not been documented to this extent and detail as a whole. The CAO covers a large area and provides levels of detail beyond what can be achieved on foot, but the question is: Can it be used in establishing a stream gauging network and determining other channel characteristics? The simple answer is no. The LiDAR output is helpful in identifying the main stream channels on the map and displaying major geomorphic features such as waterfalls and channel junctions. However, field work is still necessary to identify geomorphic features that are required to establish a stream gauge.

These include classifying the substrate, channel classification, substrate size range, slope, and degree of entrenchment. Some stream characteristics, such as sinuosity can be determined by LiDAR. The CAO data can be helpful in planning the field work, determining access points, channel paths, major channel alterations etc., but it can not serve as a replacement for the actual field work. Aside from its use in planning for stream gauging activities, the LiDAR could be more useful if collected at higher spatial resolution (e.g. << 1 m), which can easily be accomplished by flying the system at lower altitude. For the current data set, the LiDAR was flown at high altitude (12,000 ' m.s.l.) to cover the entire 4,995 hectare reserve in a few hours.

Future work is proposed for the 2008 Fiscal Year to complete the Kaawalii stream survey (including level surveys, cross-section establishment, GPS monumenting, photo documentation, channel classification, geologic substrates, pebble counts, coarse woody debris status) and complete one additional stream survey within the HETF, which also includes a baseline aquatic organism survey for the perennial stream.

ACKNOWLEDGMENTS

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COMPARING BEDLOAD CONDITIONS IN THE CASCABEL WATERSHEDS, CORONADO NATIONAL FOREST

Karen A. Koestner,[1] Daniel G. Neary,[1] Gerald J. Gottfried[2]

Oak savannas and woodlands are a significant ecosystem type of the Southwestern Borderlands spanning approximately 800,000km^2 (31,000 mi^2). However, there is little hydrologic data available to aid in the informed management of these lands (Gottfried and others 2001). Therefore, an ecosystem-scale experimental watershed study was established to study the hydrology and ecology of southwestern oak savannas, as well as evaluate the effects of cool and warm season prescribed fires on multiple ecosystem components.

Fire was the most significant natural disturbance in southwestern oak savannas prior to European settlement. However, due to past over-grazing and fire suppression practices, fire has been far less frequent on the landscape (Neary and Gottfried 2004). These management activities have caused ecosystem changes and increased fuel accumulations which could contribute to stand replacing fires (Kruse and others 1996). Prescribed fire is a proposed management technique to restore natural processes within oak savannas by reducing woody species density, increasing herbaceous plant production, and creating vegetative mosaics on the landscape. Questions concerning the seasonality of burn treatments and the overall effects of these treatments on hydrologic and ecologic processes need to be addressed prior to broad management application. Twelve small watersheds on the eastern slope of the Peloncillo Mountains of southwestern New Mexico, termed the Cascabel Watersheds, were selected to address these questions.

A collaborative research effort between the US Forest Service's Rocky Mountain Research Station and Coronado National Forest, the Malpai Borderlands Group, the Animas Foundation, the International Arid Lands Consortium, the Natural Resources Conservation Service, and their associates has amassed considerable hydrological and ecological information on the oak savannas of the Peloncillo Mountains since 2002. This paper compares changing bedload conditions between 2003 and 2006 on four of the Cascabel watersheds scheduled for treatment. This information is necessary to the understanding of hydrologic and geomorphologic characteristics of these watersheds prior to treatment. These observations are also important for they may influence the treatment assignment blocking design used for this study pending further analysis.

SOUTHWESTERN OAK SAVANNAS

This ecotype is dominant in the Coronado National Forest of southern Arizona and New Mexico covering approximately 342,800 ha (847,000 ac). These oak savanna/woodland ecosystems span elevations from 1,220 to 2,225 m (4,000-7,300 ft), with annual extremes in precipitation ranging from 305 to 1,016 mm (12 to 40 in) (Gottfried and others 2002).

Hydrologic information pertaining to the oak savannas is limited (Lopes and Ffolliott 1992). The bulk of hydrologic research in the region has been conducted in the Chihuahuan Desert near Tombstone, AZ (Osterkamp 1999). There is a lack of information concerning surface runoff characteristics in oak savannas (Gottfried and others 2002). Surface runoff is affected by spring and winter rainfall and snowmelt events; however, the majority of runoff is from high intensity summer rainfall (Gottfried and others 2002). These high intensity precipitation events can accelerate erosion and sedimentation (Hester and others 1997). Good watershed condition consisting of healthy well-stocked stands of trees and herbaceous vegetation is necessary to avoid accelerated sedimentation and erosion that could impact water quality (Lopes and Ffolliott 1992). However, due to increasing fuel accumulations in the oak savannas, there is increased potential for stand replacing

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wildfire which can have substantial impacts on watershed processes-increasing erosion, sedimentation and creating hydrophobic soils (Allen 1995).

THE CASCABEL WATERSHEDS

Twelve small watersheds were selected for study on the east side of the Peloncillo Mountains (Figure 1) in southwestern New Mexico to ascertain the impacts of cool season and warm season prescribed burning on oak savanna ecosystems. The watersheds are located north of Whitmire Canyon in the Coronado National Forest, approximately 50 km (31 mi) south of Animas, New Mexico. The watersheds range in size from 8-34 ha (20-83 ac) at elevations between 1,664 to 1,692 m (5,460 -5,550 ft). Annual precipitation at the Cascabel Ranch east of the experimental area averaged 597 mm (23.5 inches) between 1981 and 1999 (Gottfried et al. 2007).

The parent material in the study area is rhyolite-a fine-grained volcanic rock. The common soils documented in the 1991 General Ecosystem Survey of this area of the Peloncillo Mountains (completed by the Southwestern Region of the Forest Service) are generally Typic Haplustalfs, mesic, deep, gravelly loam compacted or deep very cobbly sandy-loam gullied (Neary and Gottfried 2004). The soils in the area have been classified as rock land with bedrock at 0-30 cm-however, exposed bedrock is common.

The Cascabel watersheds were selected based on their potential usefulness for addressing questions related to multiple ecosystem components of the oak

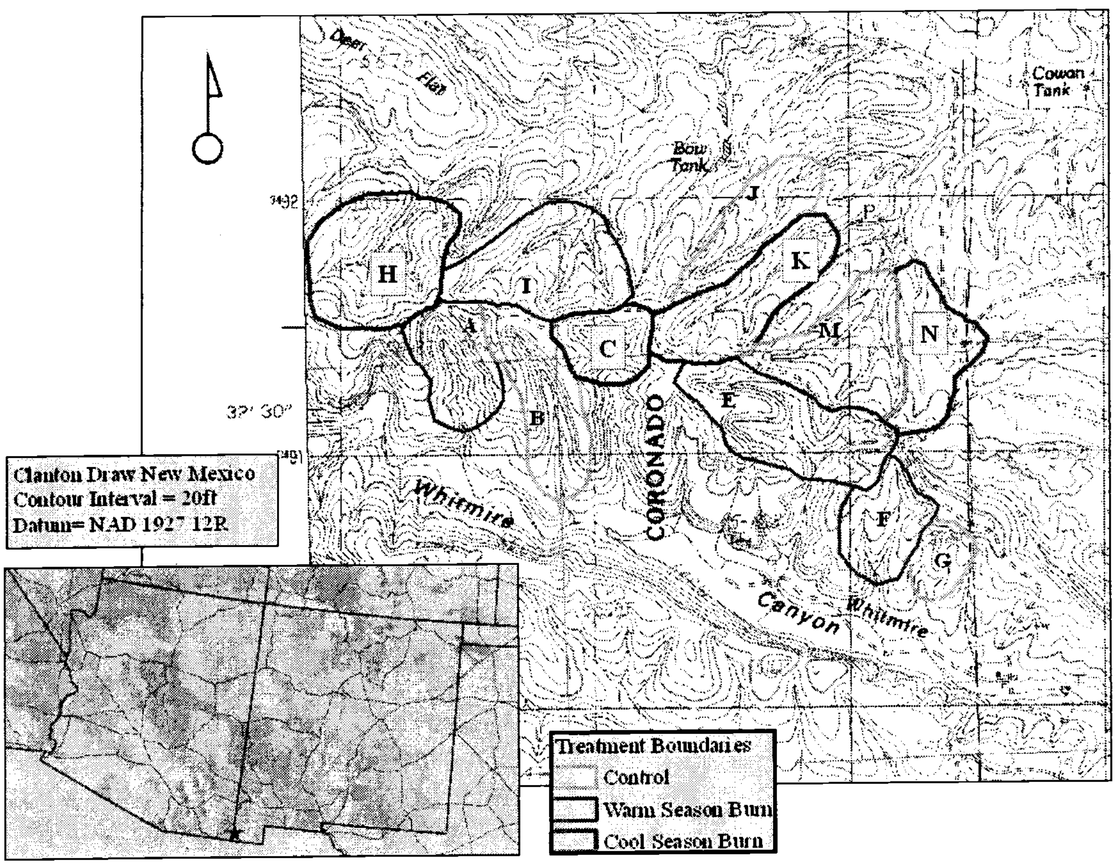


Figure 1. Watershed location and current experimental design: H, A, K, and G are controls, C, E, J, and M will be treated with a cool season burn and B, I, F, M will be treated with a warm season burn. The changing bedload conditions of watersheds H, A, N, F could result in reassignment of the treatments.

savannas such as flora and fauna, hydrological processes and soil properties. Usefulness is judged by multiple logistical and morphological factors. Watershed criteria includes the ecotype of interest (oak-savanna), accessibility, distinct channel formations (measurability), adequate gauging sites for flume installation, and being relatively similar in size, slope and elevation. The Cascabel Watersheds are representative of many oak-savannas and open woodland sites of the Southwest borderlands based on elevation, annual and seasonal precipitation, and percent of oak cover (Gottfried and others 2002). Six watersheds were selected on the north and south sides of a ridge between Whitmire and Walnut Canyons and divided into groups of three. Each group of watersheds have two burn treatments and an untreated control. Watersheds A through G are on the south-side of the ridge and watersheds H through N are on the north-side (Figure 1).

EVALUATING BEDLOADS

Changing bedload conditions for watersheds A, H, N and F are evaluated in this paper. These watersheds are on the eastern (N and F) and western (A and H) extremes of the study area. They have been selected to contrast differences in bedload conditions and total precipitation based on aspect and east/west orientation. Table 1 outlines the topographic characteristics such as elevation, area, watershed and channel slope, and aspect of selected watersheds (A, F, H and N). Bedload dynamics, which are characterized by great temporal and spatial variability, are extremely important to aid understanding of channel evolution (Renault and Regüés 2006). To gain a perspective on the changing bedload conditions, the mechanisms affecting bedloads over time and space (e.g., the flow conditions and the supply of bed-load material) must be addressed.

Ward and Trimble (2004) define bedload as sediment transported along a channel bed by a combination of sliding, rolling, and saltation that contributes to building point bars and banks in the main channel. Bedload conditions and their contributing factors are assessed here by a combination of survey methods that assess physical and morphological characteristics. Substrate cover was determined for the reach of each watershed, while channel morphological characteristics of slope and cross-section formation were collected at the permanent cross-sections. Channel cover and morphology data provide insight into the amount of erosion and sediment movement occurring over time (Ward and Trimble 2004).

A channel condition survey was completed in 2003 to determine initial substrate cover of each channel. The physical condition of the channels, whether or not they are comprised of fine sediment, vegetative cover, or long reaches of exposed bedrock, is thought to potentially have a strong influence on hydrologic response (e.g. peak flows, sediment movement, etc).

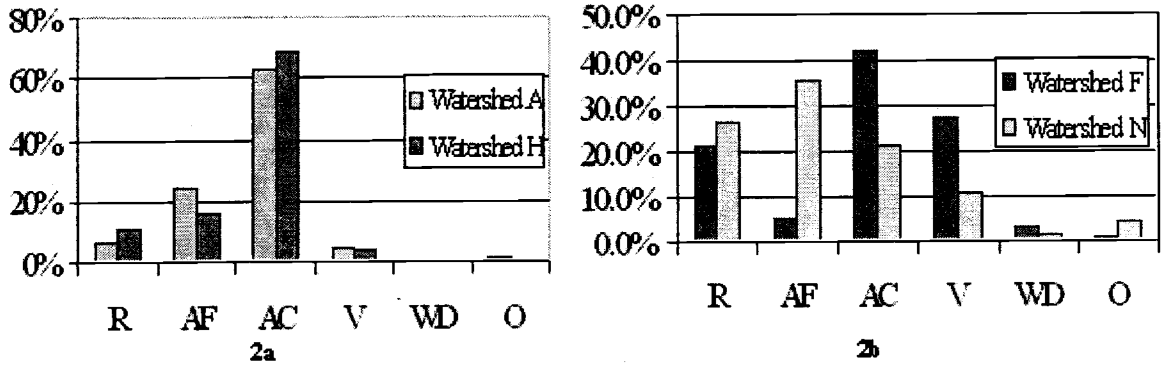
Channel condition was evaluated by completing line transect surveys in 100 m increments upstream from the sediment weir through the reach of the watershed until no distinct channel could be determined (including side channels). The substrate condition of the channel was measured and averaged by watershed (Figures 2a and 2b).

The second survey method used in the comparison of bedload conditions determines cross-sectional formation. This was measured by surveying

Table 1. Topographic characteristics of selected Cascabel watersheds, Peloncillo Mountains.

WS	*Area (ha)*	*Mean Elevation (m)*	*Mean Slope (%)*	*Channel Length (m)*	*Channel Slope (%)*	*Aspect degrees*	*T_c* (hours)*
A	13.8	1692	22.8	380	5.6	160	0.13
F	12.5	1665	16.2	429	6.4	190	0.228
H	22.3	1695	18.7	550	5	180	0.126
N	10.9	1672	9	421	3.6	360	0.283

*T_c (time of concentration) is the time it takes for runoff to travel from the most distant point of the watershed to the outlet. (Source: Gottfried GJ, Neary DG, Bemis RJ. 2002.)



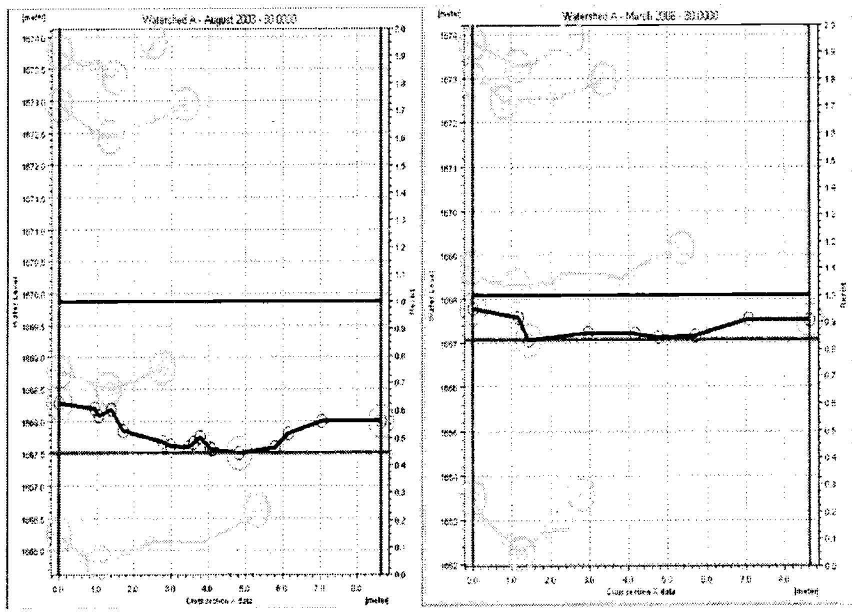
Figures 2a and 2b. Channel characteristics for western (A and H) and eastern (F and N) oriented watersheds. Substrate abbreviations used: R-rock, AF- fine alluvium sediment, AC- coarse alluvium sediment, V - vegetation, WD- woody debris, and O- other.

elevational changes in channel gradient across transects using a stadia rod and surveying level. The cross-section data were then entered into a stream channel modeling program called Mike 11 (Figures 3-6). Five cross-sections for each watershed of interest (A, H, F, and N) were modeled in two separate years between 2002 and 2006 to compare changes in bedload conditions. Elevation in meters is on the y-axis and channel width in meters is on the x-axis. The cross-section highlighted in black is the same in the side by side images and will be used to determine changing bedload conditions. The other information presented in these figures (i.e. red and blue lines) are not pertinent to this comparison and will not be discussed.

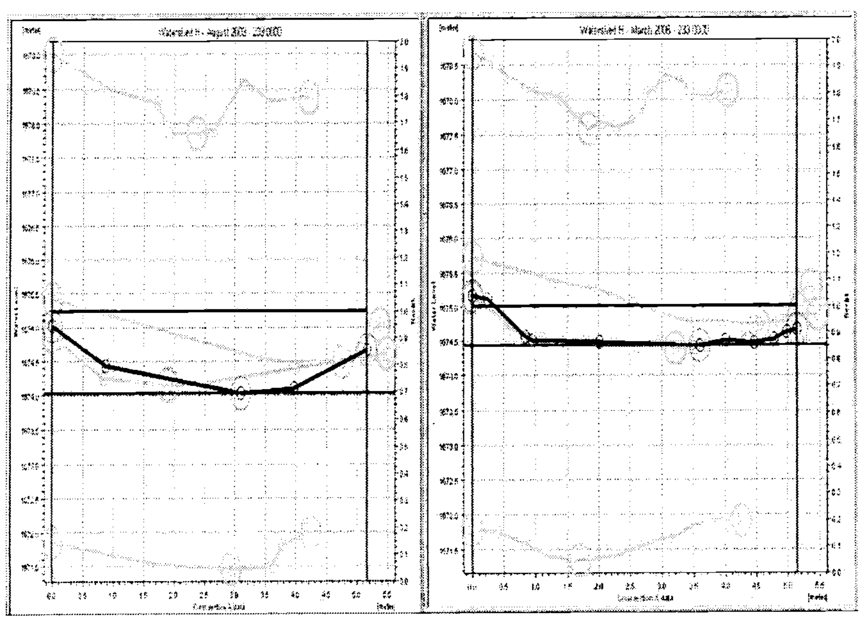
There is a visibly significant change in bedload conditions on watershed A between 2003 and 2006 (Figures 3a and 3b). The elevation of all cross-sections has risen-implying an increase in deposited sediment. Watershed H (Figures 4a and 4b) shows a similar trend as watershed A, though there is a less pronounced increase in elevation by individual cross-sections. Both of these watersheds are situated on the western portion of the study area and they have similar bedload trends. The changes are different in the eastern oriented watershed N (Figures 5a and 5b). Significant sediment accumulation only occurs upstream, which may be due to erosion or a rock slide event. Further investigation on the ground and modeling of cross-sections are needed to ascertain the causal factor. Watershed F (Figures 6a and 6b) presents another irregularity. Instead of sediment deposition, some channel incision or degradation were observed between 2003 and 2006. The causality of this will need to be determined after further analysis.

One trend that holds true for the four watersheds examined is that the watersheds on the western portion of the study exhibit more sediment transport and accumulation. The topography and size of the individual watersheds, their physical condition (i.e., channel condition), and their orientation on the landscape (east or west and northern or southern aspect) are the major variables impacting morphological changes over time as seen in the cross-section analysis. Research on coarse sediment transport by Reid and others (2007) states that certain areas of the watershed could act as key sediment sources. The inconsistent bedload conditions between the eastern and western watersheds presented here could be impacted by a greater number of sediment sources or substrate homogeneity on the western side of the study area. However, these are simply conjectures based on preliminary observations of the calibration data.

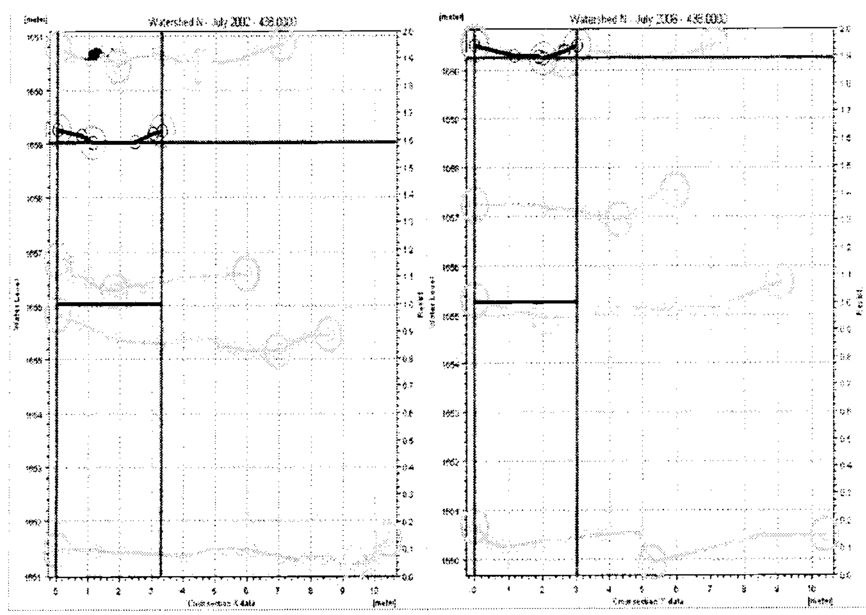
For this comparison of bedload conditions, channel condition and cross-sectional survey information were combined with the data from a high-intensity precipitation event on August 23, 2005. The objective of this bedload comparison was to determine whether or not storm/ precipitation trends correspond with the observed changes in bedload condition. Tables 2 and 3 quantify the peak flows following that precipitation event and the



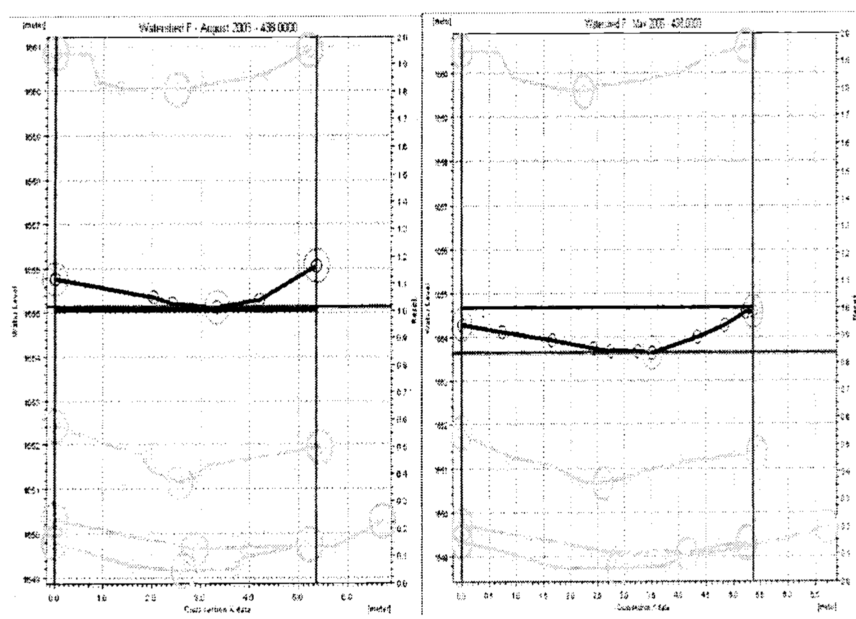
Figures 3a. and 3b. Watershed A cross-sectional model for August 2003 and March 2006, respectively.



Figures 4a and 4b. Watershed H cross-sectional model for August 2003 and March 2006, respectively.



Figures 5a and 5b. Watershed N cross-sectional model for July 2002 and July 2006.



Figures 6a and 6b. Watershed F cross-sectional model for August 2003 and May 2006.

amount and duration of precipitation on a per watershed basis. Only the watersheds of interest are presented. In the initial experimental design, watersheds were blocked into those facing north and those facing south and then replicated block treatments were assigned as shown in Figure 1. The rationale guiding this decision was that aspect (northern vs. southern exposure) will have the greatest impact on total precipitation and peak flows. However, the data in Tables 2 and 3 (which reflect average storm data on the Cascabel watersheds) show east and west orientation as a more significant factor than aspect. Peak discharge and effective runoff have considerable impacts on bedload and therefore need to be viewed in tandem (Renault and Regüés 2006). Table 3 documents typical storm movement that begins in the west and moves eastward resulting in a greater amount of precipitation and corresponding peak flows in western oriented watersheds (A and H). Although aspect appears to be a factor there is less variation between watersheds on north and south slopes (A and H, N and F) as is between watersheds on east and west sides of the study area (A and F, H and N).

Table 2. Peak storm flows, August 23, 2005

Southern Aspect	Peak Flow (cfs)	Peak Flow (cms)	Northern Aspect	Peak Flow (cfs)	Peak Flow (cms)
A	67.2	1.903	H	76.8	2.175
F	24.6	0.697	N	31.3	0.886

Table 3. Precipitation for August 23, 2005

Weather Station	Total Precipitation (inches)	Total Precipitation (cm)	Start Time	End Time
H	2.36	5.99	12:00	16:00
A-B	2.64	6.71	12:01	15:44
F-G	1.36	3.45	12:09	15:49
N	1.43	3.63	12:21	15:52

The changes observed in cross-section analysis match the variation in precipitation data remarkably well, although they require further analysis. The information presented here is a relative comparison of cross-section changes over time and does not actually quantify the amount of sediment movement that has occurred.

CONCLUSIONS

This preliminary assessment of bedload conditions in the Cascabel watersheds highlights some important factors for consideration regarding this research project and watershed research as a field. Further analysis and modeling should be completed prior to the planned treatments. The data presented here support a reassignment of replicated blocks based on an east/west boundary instead of a north/south one. However, this requires complete cross-sectional modeling, some time-series analysis and an analysis of covariance to determine the most important sources of variability between watersheds during the calibration period. Utilizing calibration data pre-treatment and continued monitoring post-treatment are an attempt to increase the knowledge of the hydrologic and ecologic processes of southwestern oak savannas to improve overall land stewardship for a myriad of private and public stakeholders.

Observing bedload changes during the calibration period further supports an adaptive and flexible approach to the experimental design used in a paired-watershed study to achieve multiple objectives and decrease variability between replicates. By examining these data prior to prescribed fire treatments, we are able to improve the design of this study, and therefore provide more conclusive data for land managers. The initial analysis also provides support for gathering and utilizing substantial calibration data prior to treatment application.

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CHARACTERISTICS AND BEHAVIOR OF A COOL-SEASON PRESCRIBED FIRE IN THE OAK SAVANNAS OF THE SOUTHWESTERN BORDERLANDS

Karen A. Koestner,[1] Daniel G. Neary,[1] Gerald J. Gottfried,[2] and Ruben Morales[3]

Oak-savannas and woodlands comprise over 80,000 km^2 (31,000 mi^2) in the mountains and high valleys of the southwestern United States and northern Mexico (Figure 1). Fire, which was once the most important natural disturbance in this system, has been excluded due to over-grazing and fire suppression practices. This has resulted in ecosystem changes and fuel accumulations. Prescribed fire is one management technique to restore natural processes within southwestern oak-savannas by reducing woody species density, increasing herbaceous plant production, and creating vegetative mosaics on the landscape. Seasonality of burn treatments and their effects on physical and ecological processes need to be determined prior to broad management application. The Cascabel Watershed Study is a collaborative interdisciplinary study to determine the effects of cool-season and warm-season prescribed burning on a southwestern oak-savanna ecosystem. Twelve small watersheds in the Peloncillo Mountains of southwestern New Mexico have been monitored for seven years to provide hydrologic data prior to prescribed burning treatment application (Figure 2). These watersheds are grouped in four replicated blocks, each consisting of a cool-season treatment, a warm-season treatment and a control watershed. This paper will discuss the characteristics and behavior of the cool-season burn treatment, summarizing burn intensity and severity estimates.

SOUTHWESTERN OAK SAVANNA VEGETATION

Multiple species of oaks are found in the southwestern oak savannas, however Emory oak *(Quercus emoryi)*, Arizona white oak (*Q. Arizonica*), and Toumey oak (*Q. toumeyi*) are the most prevalent species in the Peloncillo Mountains (Brown 1982, Ffolliott and Gottfried 2005). These oaks are typically small, multi-stemmed, and irregularly formed with variable stand densities (Gottfried et al. 1995). The oak species native to this region are fire enduring-experiencing top kill / shoot mortality but sprouting following fire (Barton 1999). However, periodic fire is required to limit establishment and growth of woody species in savannas and allow for herbaceous competition (Van Auken 2000). Alligator juniper (*Juniperus deppeana*) is also a common overstory species in this region. Redberry juniper (*Juniperus coahuilensis*), pinyon (*Pinus cembroides*), and velvet mesquite (*Prosopis velutina*) are lesser components of the oak-savanna overstory (Ffolliott and Gottfried 2005).

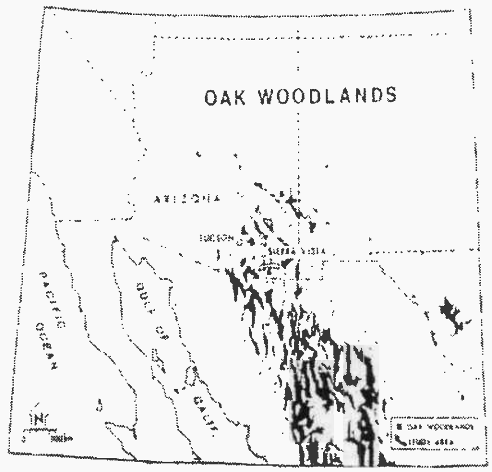

Figure 1. Extent of Southwestern oak woodlands and savannas. (Source: Brown and Lowe 1980.)

The savanna or grassland component of this ecotype has multiple bunch grass species including blue (*Bouteloua gracilis*), sideoats (*B. curtipendula*), slender (*B. filiformis*), and hairy (*B. hirsuta*) grama, bull muhly (*Muhlenbergia emersleyi*), wolftail

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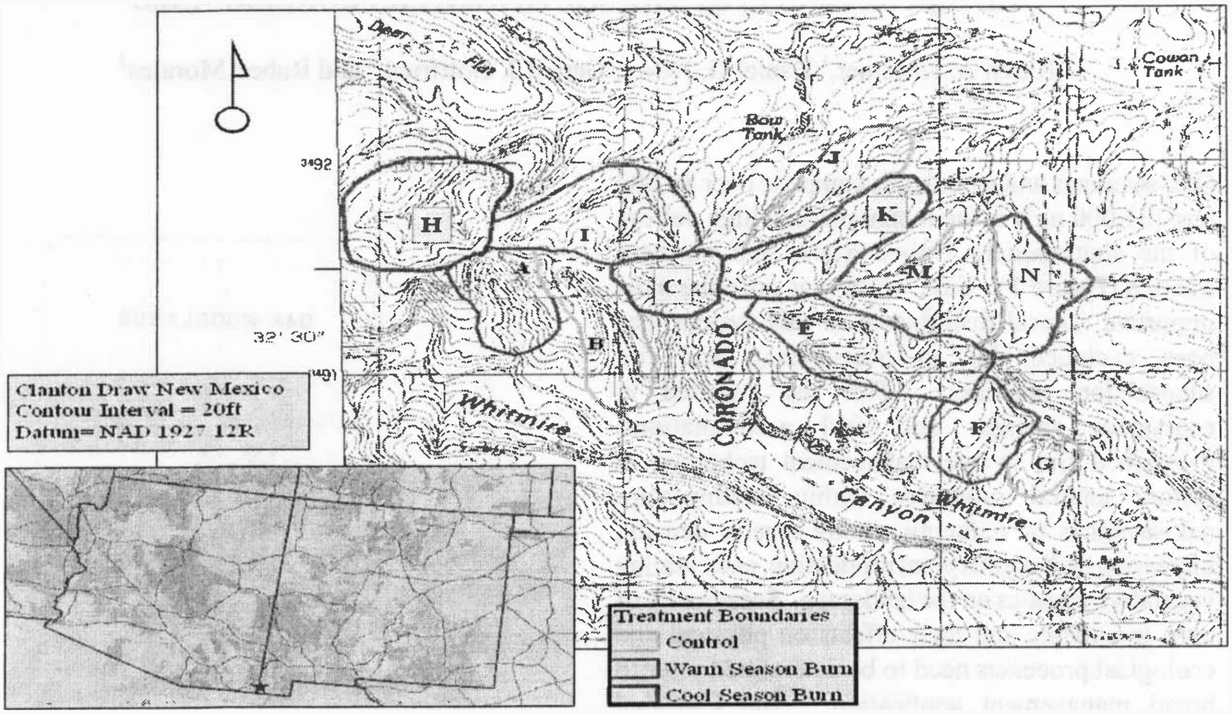

Figure 2. Cascabel watershed study area and treatment designations. Watersheds H, C, K, and N were burned in March 2008 for the cool-season treatment component of the Cascabel watershed study.

(Lycurus pheoides), and Texas bluestem (*Schizachrium cirratum*) (Brown 1982, Ffolliott and Gottfried 2005). Some forbs including Fendler ceanothus (Ceanothus fendleri) and Mexican cliffrose (*Pushia Mexicana*) can be found in southwestern oak savannas. Intermixed shrub species include Beargrass (*Nolina microcarpa*), fairy duster (*Calliandra eriophylla*), sotol (*Dasylirion wheeleri*), and manzanita (*Arctostaphylos spp.*). Yucca (*Yucca spp.*) and agave (*Agave spp.*) are also scattered throughout the oak-savanna ecotype.

Woody species (mostly oaks) have increased in both density and total cover on the landscape (Hester et al. 1997, Van Auken 2000). Native woody plant (oaks) encroachment has also decreased the cover of perennial grasses (Van Auken 2000, Ottmar et al. 2007). Woody encroachment is the result of both environmental conditions and management practices. Grasses inhibit woody species during early phases of growth, but are out-competed once the roots of woody plants are below the root zone of grasses, a situation that is maintained by fire exclusion (Van Auken 2000, Webster et al. 2001).

FIRE IN THE BORDERLANDS

Fire has been a central component of the development of all southeastern Arizona ecosystems (Allen 1995). Prior to the 1890s wildfires were common in the Southwestern borderlands whenever sufficient fuel loads were present. These were both lightning and anthropogenic fires (Bahre 1991) generally occurring in drought years following a wet period when there was large increase in herbaceous growth (Allen 1995). Fire would typically burn in the dry lightning season from May to July prior to summer monsoons with low severity impacts (Gottfried et al. 2001). The presence and importance of fire on this landscape is further attested to by tree-ring fire scars at higher elevations, the rapid post-fire recovery and/or enhanced vegetation, historic records, and the high frequency of summer lightning ignitions (Bahre 1991).

Fire exclusion for the past century in this region has had considerable ecological effects (Kruse et al.

1996). The historic fire regime in savanna ecosystems is estimated as four to eight years prior to European settlement (Kaib et al. 1999). Several dominant species such as Emory oak and Arizona white oak are adapted to fire and will sprout after their tops have been killed off, though severe fire results in mortality (Ffolliott and Bennett 1996, Barton 1999). Fire exclusion has resulted in fuel accumulation and increased stand densities (Hester et al. 1997). These conditions increase the probability of stand-replacing high-severity wildfires (Gottfried et al. 2002).

Prescribed burning is a potential treatment technique to restore pre-European settlement conditions within the oak savannas (Gottfried et al. 2002). Restoring a more "natural" composition includes density reduction of woody species, increasing herbaceous plant production, and creating mosaics of vegetation on the landscape. Currently however, there is limited information concerning the impacts of prescribed fires on southwestern oak savannas (Barton 1999). The seasonality of fire is an important characteristic because it determines whether or not vegetation will burn during the dormant (cool) season in winter/spring or during the summer growing (warm) season. Brockway et al. (2002) documented grassland response to dormant or cool season fire with an increase grass cover, forb cover, and species richness. While growing or warm season fire reduced graminoids and forbs cover and increased litter cover. Variable removal of vegetation cover and exposure of soil between seasonal burn treatments may alter watershed functioning by increasing erosion, sedimentation and peak flows (Neary et al. 2005). Therefore, if prescribed fire is going to be adopted as a functional management technique in the southwestern border lands, the effects of prescribed fire on the now overstocked oak savannas, and the effects of fire season need to be determined.

COOL SEASON BURN TREATMENT

Watersheds N, H, K, and C were burned in March of 2008 fulfilling the cool-season treatment component of the Cascabel watershed study (Figure 2). The objective of this treatment was to blacken 50-75% of the watershed surface area with a cool-season burn at varying severity across the designated watersheds. Up to 60-70% of shrubs within the oak-savannas were to be eliminated as well as the top kill of 25-40% of overstory species. The treatment prescription also called for the reduction of 1 hr (by 30-80%), 10 hr (by 10-40%), 100 hr (by 1-10%), and 1000 hr (by 1-20%) fuels in the watersheds. The environmental prescription for this burn required that temperatures fall between 50-105° F (day) and 30-70°F (night) with relative humidity ranging from 4 - 30%.

This was the first experimental burn treatment on the Cascabel watershed study to determine the impacts of cool vs. warm-season prescribed fire on Southwestern oak-savannas. The overall purpose of the burn is the reduction of hazardous fuels, while maintaining fire's natural role in the Peloncillo Mountains. Continued monitoring of post-fire response to determine the effects of cool and warm season prescribed burning on hydrologic and ecologic processes will be addressed in future studies.

DETERMINING BURN INTENSITY AND SEVERITY

Burn intensity is the heat produced per unit length of fireline during combustion of a given fuel (Pyne et al. 1996, Neary et al. 2005). Intensity was measured by two methods: infrared thermometer guns and temperature indicating paints. Infrared thermometers were used to take temperatures of different fuels during combustion. Table 1 summarizes the range of temperatures exhibited by various fuels. The ranges of values displayed in Table 1 (minimum to maximum burn temperatures by vegetation type) are extremely variable between fuel types with litter and light grass combusting at the lowest average intensities. Yucca, which burned at the highest intensity, had minimal cover on the landscape and was not typically combusted to the soil surface. Whereas bear grass, which burned at medium to high intensities was typically burned right to the soil surface. The range of burn intensities measured for each vegetation type are due to the time in the combustion process when the temperature was recorded, and the wind speed and direction at that time. The values provided are a

Table 1. Burn intensities of various vegetation types as measured with infrared thermometer guns during the cool-season burn treatment, March 2008.

FUEL	AVERAGE TEMP - °C	MINIMUM TEMP - °C	MAXIMUM TEMP - °C	AVERAGE TEMP - °F	MINIMUM TEMP - °F	MAXIMUM TEMP - °F
LITTER	293.0	293.0	293.0	559.4	559.4	559.4
LIGHT GRASS	463.3	150.0	900.0	865.9	302.0	1652.0
AGAVE	481.5	382.0	581.0	898.7	719.6	1077.8
JUNIPER	586.7	216.0	858.0	1088.1	420.8	1576.4
YUCCA	620.7	225.0	997.0	1149.3	437.0	1826.6
HEAVEY GRASS	638.3	292.0	863.0	1181.0	557.6	1585.4
OAK	657.6	237.0	945.0	1215.7	458.6	1733.0
BEAR GRASS	658.6	164.0	887.0	1217.5	327.2	1628.6
MANZANITA	692.6	542.0	828.0	1278.6	1007.6	1522.4

general characterization of burn intensities of different vegetation types during a cool-season prescribed burn in Southwestern oak-savannas.

Ceramic tiles with temperature indicating paints ranging from 200° F to 2000° F (93° C - 1093 ° C) in intervals of 100° F (38 ° C) were placed under various fuel types. The full range of temperature indicating paints were on each tile (200° F to 2000° F) and three tiles were placed beneath each fuel class. When the paint reaches its indicating temperature it liquefies. The fuel types/location used were: light grass (LG), heavy grass (HG), bear grass (BG), oak (O), woody debris (WD), and the watershed channel (C). A full range of burn temperatures were indicated by the paints from <200° F (no liquification) beneath light grass, unconsumed fuels, and in the watershed channel to 2000° F beneath woody debris that was still smoldering the day after the burn. Interpreting the temperature indicating paints was often obstructed by ash. This was not a useful determinant of burn intensity due to the fact that the fire often missed the fuels under which the tiles were placed, and the discrepancy in interpreting at which temperature the liquification occurred.

Fire severity is the effect that fire has on the environment-a characterization applied to multiple ecosystem components (Neary et al. 2005, Van Wagtendonk 2006). For this initial estimate of cool-season burn severity on the Cascabel watersheds, the severity of the burn at the soil surface was considered. Soil burn severity was measured under the same vegetation classes as intensity, at the location where the tiles with temperature indicating paints were placed. This was done to provide a means to compare burn intensity and severity beneath various fuel classes. Using the soil burn severity index outline by DeBano et al. (2005) soils were classified as low, moderate or high severity post-burn. The descriptions of each characterization are: low severity burn: duff largely intact, light ground char, woody debris are partially consumed, mineral soil unchanged. moderate severity burn: litter consumed, duff charred or consumed, woody debris mostly consumed (except logs), gray - white ash present. high severity burn:

duff is completely consumed, top of mineral soil is reddish or orange, logs consumed or deeply charred

The cool-season burn was largely low severity. However, moderate severity was commonly exhibited beneath beargrass clumps, and moderate to high severity beneath consumed or smoldering woody-debris.

Another indicator of severity on post-burn soil properties is water repellency. Soil water repellency (WR) is a property the can be modified by the combustion of litter and organic matter, which can then impact the infiltration of water into the affected soil (DeBano et al. 2005). Determining the occurrence of WR is important as water-repellant soils can result in increases in runoff and erosion. WR was tested using Water-Drop Penetration Time (WDPT), which is the time it takes a drop of water to completely infiltrate into mineral soil. WDPT was extremely variable beneath all fuel types ranging from instantaneous to greater than 2 min at adjacent test locations at mineral soil. However, WDPT 1 cm below the soil surface ranged from instantaneous to 20 sec. Therefore, the impact of the cool-season burn treatment was minimal to non-existent on soil-water repellency across vegetation types.

CONCLUSIONS

The results summarized in this paper represent initial intensity and severity estimates for a cool-season burn in Cascabel watersheds. The findings indicate that although combustion temperatures (intensity) are high and variable between fuel types, soil severity and soil-water repellency is generally low to moderate following a cool-season prescribed burn in oak savannas of the Southwest. High combustion temperatures do not necessarily result in a high severity burn. To minimize the impacts of prescribed fire, the residence time of a prescribed burn needs to be reduced.

Prescribed fire is a management tool that has potential to restore "natural" species compositions and densities. However, the physical and ecological effects of prescribed fire need to be determined to support environmental analyses of landscape level fire programs. Furthermore, the burn intensity and severity data presented here provides managers an expected range of fire behavior and its effects by fuel type.

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HYDROLOGY AND EROSION IMPACTS OF MINING DERIVED COASTAL SAND DUNES, CHAÑARAL BAY, CHILE

Daniel G. Neary[1], and Pablo Garcia-Chevesich[2]

Chile has an economy strongly based on the exploitation of its natural resources. Copper mining represents the main export monetary income, employing thousands of people all along the country. The Chilean Copper Corporation (CODELCO), El Salvador branch, has been the primary mining company, but it will be ending most of its activities by 2011 unless copper prices stay at their record levels. Besides the job consequences for the local population, there are some serious environmental issues that must be solved during the shut-down.

Nearly 12 km^2 of contaminated sand dunes, located in the Bay of Chañaral, Chile, are the result of mining operations between 1938 and 1975 that released contaminated sediments to the bay. Even though the sediment release no longer occurs, the coastal winds transport the heavy metals attached to the sand grains over the town of Chañaral. This area is arid desert, with no more than 10 mm/year of precipitation. Between 1938 and 1990, more than 300 million Mg of highly contaminated residual sediments were deposited in the Pacific Ocean. The chemical analyses of the sediments have shown high contents of cupper, iron, arsenic, zinc, cyanide, lead, aluminum, mercury, molybdenum, and other heavy metals. The toxic metals inside the sediments as well as the arid nature of this portion of the Atacama Desert have affected the establishment of almost any vegetation.

As a consequence of the exposure to the toxic mining tailings dust produced by the coastal winds, there is a high incidence of skin, lung, and eye problems in the local human population, as well as a high incidence of cancer tumors. Even though there have been some attempts at stabilizing the contaminated sand dunes, none have succeeded. The most practical solution appears to be to stabilize of the sand dunes with multiple row tree shelterbelts next to the town of Chañaral. This paper examines the hydrologic processes which formed the sand deposits and the potential remediation program.

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STUDY AREA

Copper Mining

Chile is world's largest copper producer. Cuprous porphyry ore bodies that exist along the Andean Cordillera are responsible for Chile's vast mineral reserves. Some of the world's largest opencast mines are located at high altitudes and harsh cold and arid environments along the Andes Cordillera. During 2004 Chile's copper production reached 5.3 million Mg. Other metallic minerals mined and smelted in Chile include gold, silver, molybdenum, zinc, manganese and iron ore.

Copper mining has been important to Chile's economic development since the arrival of the Spanish conquerors in the 16th century. Between the 1840s and the 1880s, Chile's share of the world's copper-mining production rose to about 50%. Its share decreased to only 5% in the first half of the 20th Century, but now is expected to rise to 35–40% by 2010. Copper production in Chile reached 35% of the world market in 2000 (Velasco 2000). During the last decade, this activity has accounted for about 50% of the country's exports and foreign investment, about 5–7% of the gross national product, but less than 2% of the labor force. Copper is the main export, followed by gold, silver, molybdenum, iron, nitrates, iodine, and lithium. Some of the gold and silver and all of the molybdenum are produced as by-products of copper mining.

Most of the copper mines in Chile are located in the Andes Mountains, many in the arid to semi-arid Atacama region of the country. The three most important are: Chuquicamata at 2,680 m above sea level (22 ° 19' South Lat.; 68 ° 56' West Long.). El Salvador at 2,600 m above sea level (26 ° 15' South Lat. S.; 69 ° 34' West Long.) and El Teniente at 2,113 m above sea level (34 ° 04' South Lat.; 70 ° 21' West Long.). The environmental impact of metal mining activities has received world wide attention (Castilla and Nealler, 1978). In two of the large Chilean copper mines, Chuquicamata and El Teniente, pollution control is obtained by the discharge of waste waters into tailing ponds. However, throughout the history of the E1 Salvador mine, all untreated mining wastes have been discharged through a semi-artificial canal directly to the Pacific Ocean shore.

El Salvador Mine

El Salvador is an open-pit mine, developed by block caving techniques (Camus and Dilles 2001). After milling, minerals are concentrated by basic flotation. A copper sulphide concentrate (CuS; CuS2) is produced by the flotation process and transferred to the molybdenum concentration plant for the separation of molybdenum sulphide by differential flotation. The latter process requires the use of arsenic and sodium sulphide, cyanide and lime as collectors of molybdenum sulphide and depressants of copper sulphide. The copper concentrate is then sent through a pipe to the current refining plant at Potrerillos. Daily use of water in the mining and processing stages at El Salvador is 65 x 10^6 L/day of water (2.5 x 10^3 L of water per ton of ore processed). Water is obtained from Andean groundwater resources. Excluding the water utilized at the molybdenum concentration plant, 40% of the water is recovered and recycled.

Chañaral Bay

Chañaral Bay is situated in on the Pacific Coast of the Atacama Desert. This desert is a virtually rainless plateau along a 1,000 km strip of land on the Pacific coast of South America, west of the Andes Mountains. The rain shadow on the leeward side of the Andes keeps this 20 million-year-old desert 50 times drier than California's Death Valley. The Atacama is the second-driest desert in the world, after the McMurdo Dry Valleys of Antarctica. It occupies 181,300 km^2 square kilometers (70,000 mi^2) in northern Chile, and consists of mostly of salt basins, sand, and lava flows. Chañaral Bay averages 20 m in depth, and doesn't deepen much until about 8 km off-shore. Chañaral is the capital of the Chañaral Department, in the Atacama region. It is 120 km northwest of Copiapó, and had a population 10,000 in 1996. It was once an important shipping center for copper produced at the Potrerillos, Las Animas, and El Salado mines, but pro-gradation of the beach with the deposition of mine tailings ruined the harbor.

. The population depended on copper industry related jobs. It declined in the 1990s with the downturn in the copper industry, but may be rebounding with surging world-wide copper prices.

HYDROLOGY

The Rio Salado collects precipitation from the Andes and the Intermediate Depression of the Atacama Desert before flowing to the Pacific Ocean (Montti 1973, International Mountain Society 1984). Rainfall in the Depression is only 5 mm but it increases with altitude, reaching 33 mm at Potrerillos (elevation 2,850 m). The Rio Salado is the only permanent river in the area with an average discharge of 10 L/sec. In the vicinity of Llanta, discharge from the El Salvador Mine is added to the river.

The majority of water use in the Atacama Region (70%) is from mining. Most of this water resource is groundwater. The effects of mining withdrawals are poorly understood. The total wastewater discharge from the El Salvador Mine reaches 39 x 10^6 L/d containing an average of 25 x 10^3 Mg/d suspended solids. Tailing discharges from the copper and molybdenum concentration plants are routed through a 25 km long canal which discharges at the locality of Llanta into the bed of Rio Salado (Figure 1). At Llanta and Pueblo Hundido, additional recovery of copper pyrite is performed by flotation. Urban waste waters after treatment at the El Salvador sewage treatment plant are canalized 50-55 km downstream before meeting, at Pueblo Hundido, the tailing discharge stream (Rio Salado). From then on, a single stream carries both types of residues to the site of dumping in the coastal area of Chañaral. From 1938 to 1974 tailing and waste waters discharged directly into Chañaral beach (Figure. lb). Since February 1975, a new canal collects discharges from Rio Salado, 8-10 km off Chaharal beach and carries them to a new dumping site at Caleta Palito.

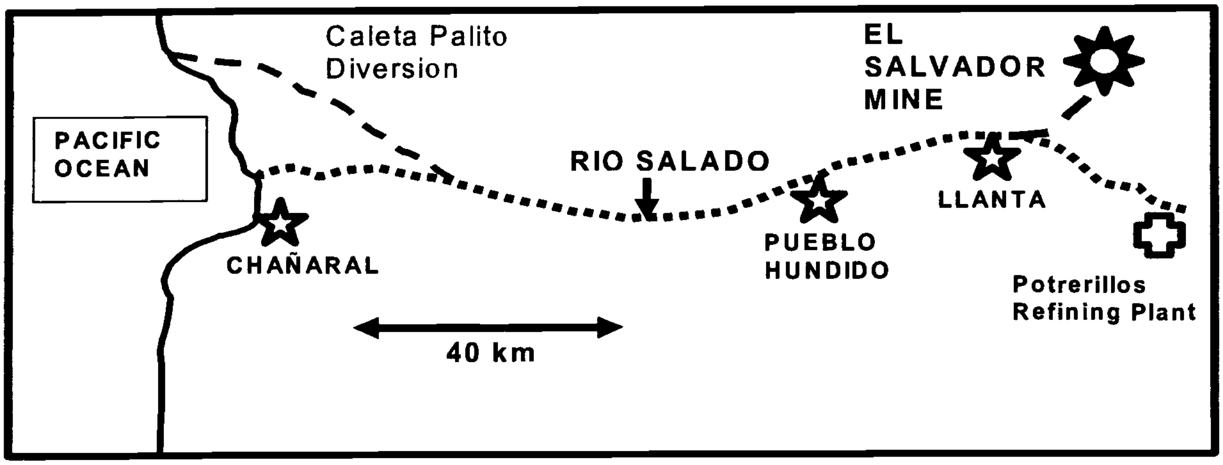

Figure 1. Chañaral Bay area of the Pacific Ocean, Rio Salado, and the El Salvador Mine, Atacama Desert, Chile.

The case of the Salado river was different. This river received tailings from the mineral-processing plant of the El Salvador mine, owned by CODELCO. The tailings completely filled in a stretch of beach in Chañaral Bay about 1 km wide and 4.5 km long. Minerals in the tailings resulted in extensive marine organism mortality (Castilla and Nealler, 1978). The El Salvador tailings dam had been filled in the original tailings dam, and the mining company, which then belonged to a US firm, allowed the tailings to spill into the Salado River. In 1975, the mining operation, which was by that time owned by CODELCO, constructed a canal to divert the river water, including tailings, to another bay, Caleta Palitos, but this action produced the same deposition effect there. Overall, the mining operation dumped 330 x 10^6 Mg of tailings into the river and the canal before it was forced to change its tailings-management practices in 1989. Until 1975, more than 150 × 10^6 Mg of untreated tailings were continuously discharged, directly affecting more than 20 km of coastline (Castilla, 1983; Paskoff and Petiot, 1990). From 1976 to 1989 the discharge point was moved 10 km north of Chañaral Bay to Caleta Palito (26°16'S, 70 °41'W), a rocky cove that received ≈130 × 10 ^{6} metric tons of tailings in 13 years. After the construction of an inland sedimentation dam in 1990, sediment-free wastewaters have been channeled from the dam to Caleta Palito at a flow rate of 200–250 L/s (Medina et al., 2004).

In the late 1980s, an environmental group from Chañaral took CODELCO to court. The court in Copiapó ordered the company to construct a new tailings dam. In 1989, the Supreme Court ratified the decision, and CODELCO was forced to build a tailings dam, which has now entered into operation. This was an important precedent in Chilean law: despite the outdated environmental laws covering liquid effluent, companies, even state-owned companies, could be taken to court and forced to deal with environmental problems. This case dealt with the most serious environmental impact of mining on river or sea waters in Chilean history, and it illustrates clearly that environmental policy was not a priority for CODELCO until very recently.

SEDIMENT DEPOSITS

Mine Tailings

Mine tailings deposited at Chañaral originate from volcanic deposits of the El Salvador-Poterillos district, located around 120 km east of Chañaral in the Atacama desert. From 1926 to 1959 the Poterillos porphyry copper deposit was mined. Hypogene alteration led to a feldspar-biotite-chlorite-quartz-ankerite-anhydrite mineralization with chalcopyrite, pyrite, bornite, molybdenite, enargite, and sphalerite as sulfide mineral assemblage (Gustafson and Hunt 1975, Camus and Dilles 2001). After 1959, the El Salvador deposit was exploited. The primary mineralization of the ore body in the 41 million-year-old El Salvador deposit is characterized by alkali feldspar-biotite-anhydrite-chalcopyrite-bornite and chalcopyrite-pyrite mineral assemblages. Supergene enrichment formed an ore body of 1.5 km diameter and a thickness of 200 m, with replacement of chalcopyrite and bornite by mostly chalcosite and covellite (Gustafson and Hunt, 1975). Tailings deposited at Chañaral were from the secondary enrichment zone. The alkaline (pH 10.5) flotation process used for Cu and Mo extraction was controlled by lime addition and the resulting tailings were the ones ultimately deposited in Chañaral Bay.

Chañaral Bay

Until 1975, mine tailings were sent into the bay at Chañaral, covering 4.5 km^2 (Figure 2). This resulted in a displacement of the shoreline of 1 km and the accumulation of a 10-15 m thick layer of tailings on top of the original beach sediments. The deposition point at the outlet of the Rio Salado migrated northward during the deposition period to the upper end of the "new" beach (Figure 2). The tailings originated from the Potrerillos mine from 1926 until 1939, and thereafter from the El Salvador mine until completion of the inland sedimentation dam in 1989. Between 1975 and 1989, tailings were sent to the sea at Caleta Palito, 8 km north of Chañaral, and were exposed to the marine current. The tailings deposition through the natural Rio Salado (the salty river) ceased in 1989 because of the court decision. Today, the tailings are deposited close to the "El Salvador" mine in the "Pampa Austral" tailings impoundment. Only the coarse sediment free waters of the settling pond at the Pampa Austral impoundment are mixed with highly mineralized waters in the Rio Salado riverbed close to the El Salado village. These waters are still discharged to the sea at Caleta Palito.

Wind Erosion

There are about 12 km^2 of tailings-contaminated sand dunes, located on the recent Chañaral beach, as well as the original pre-1938 beach. Even though new sediment release no longer occurs, the coastal winds transport the heavy metals laden sand grains over the town of Chañaral.

A single, permeable row of concrete barriers was installed next to houses and along the beach with the intention of "detaining" blowing sand. However, the aerodynamic characteristics of the barrier increases wind velocities just above the dune surface, producing even more sediment wind transport. Besides, with only one row, eddy turbulences are created due pressure differentials on both sides of the barrier. This results in sediment accumulation and burial of the barrier in newly-forming sand dunes.

Several approaches have been proposed to stabilize the mine tailings sand dunes. The sediments could be easily stabilized if the wind was gradually forced to rise over permeable barriers. The strong coastal winds blowing a few meters above the sand dune surfaces would be less likely to transport sand grains. Tree shelterbelts have been proposed as a mitigation measure for the beach wind erosion. However, soil would need to be imported due to the contaminated nature of the Chañaral sands, and water would need to be applied via an irrigation system due to the arid nature of the climate (<10 mm rainfall per year).

HEALTH IMPACTS

Mine tailings can cause human disease via exposure routes of water, dust, and crops. Diseases can range from direct toxicity to physical effects, silicosis, hypothyroidism, etc. Chemical analyses of the Chañaral Bay sediments have shown the existence of high contents of copper, iron, arsenic, zinc, cyanide, lead, aluminum, mercury, molybdenum, and other heavy metals. As a consequence of the exposure to the toxic dust produced by the coastal winds, there is a high incidence of skin, lung, and eye problems, as well as a variety of cancer tumors among Chañaral's population (Leon 2001). Concerns about perchlorate in Chañaral's drinking water affecting thyroid function of children were never validated (Crump et al. 2000).

SUMMARY

Nearly 12 km^2 of contaminated sand dunes, located in the Bay of Chañaral, Chile, are the result of mining operations at the El Salvador Mine between 1938 and 1975 that released contaminated sediments to the bay via the Rio Salado. About 150×10^6 Mg of untreated tailings were deposited in Chañaral Bay before a diversion was put in place

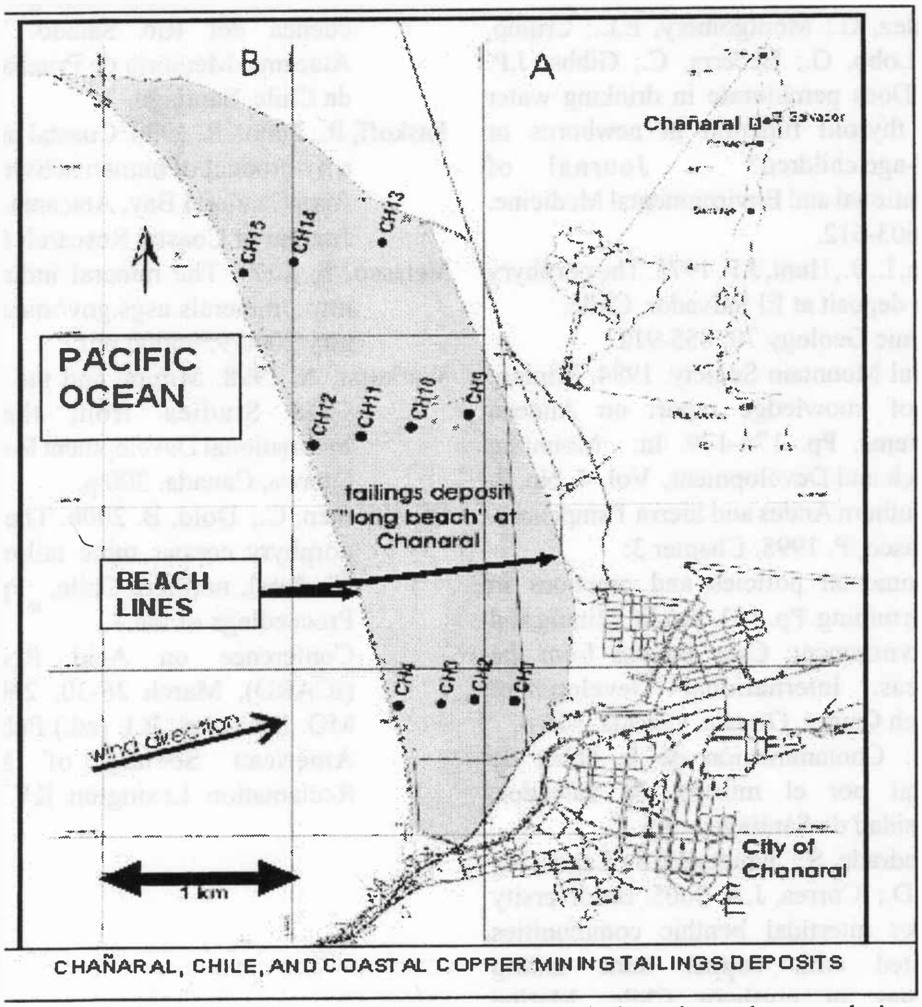

Figure 2. Chañaral Bay, Chile (A), showing beach deposits and progradation (B) from 1938 to 1989 (Adapted from Wisskirchen and Dold 2006)

Chañaral Bay before a diversion was put in place to Caleta Palito. Another 180×10^6 Mg of tailings was deposited in the Pacific Ocean before a large tailings dam was constructed at the mine. The total wastewater discharge from the El Salvador Mine reaches 39×10^6 L/d, resulting in a flow in the Rio Salado of 200–250 L/s. Even though the sediment release no longer occurs because of the diversion north of Chañaral Bay, the coastal winds transport the heavy metals attached to sand grains over the town of Chañaral. The source of these sands is 4.5 km^2 of beach formed since 1938. Biological stabilization of the sand dunes is complicated by the arid climate and toxicity of the sands.

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CLIMATE CHANGE IMPACTS ON MUNICIPAL, MINING, AND AGRICULTURAL WATER SUPPLIES IN CHILE

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Agricultural and municipal water supply interests in Chile rely heavily on streams which flow from the Andes Mountains. The highly productive Copiapó agricultural region, on the southern edge of the Atacama Desert, is a major supplier of fruit and other crops for the Northern American market during winter. This region relies entirely on snow and ice-melt streams to provide irrigation water. Santiago, the Chilean capitol, is the country's major metropolitan area with a population of 5.5 million. Rainfall that averages 330 mm/year is nearly twice that of Phoenix.

Santiago is very similar to Phoenix in a number of ways. It has a rapidly expanding population of 5.5 million, and it relies on water supplies derived from surrounding or more distant mountain ranges. Santiago and Phoenix are located at similar latitudes north and south of the equator (33°27' South for the former and 33° 31' North for the latter). Recent changes in the climate in South America are resulting in decreased snowpacks and glacier volumes in the Andes Mountains. This paper discusses the current water supply situation in Chile in light of its growing demand for water and declines in supply due to climate change.

CLIMATE AND ECOSYSTEMS

Chile has one of the widest ranges of climates and ecosystems in the world because of its north-south latitude range (4,300 km from 17 ° to 56° South Latitude) and large altitudinal gradient (0 to 6,880 m) in a short distance from the Pacific Ocean (<240 km ocean to Andes Mountains crest). It contains arid deserts, semi-arid deserts, Mediterranean-like areas, humid subtropical regions, temperate zones, oceanic-dominated climates, sub-polar areas, alpine tundra, and ice caps. These climates are often combined into the arid North, the Mediterranean Central, and cool and wet South zones. Chile is home to one of the driest deserts in the world, the Atacama Desert, where rainfall averages less than 1 mm/year, and one of the wettest regions on the planet, Isla Chiloé (>4,000 mm/year) (Table 1). The climate is characterized by a wet winter (May to August) and a dry summer (November to March). Mean annual temperatures range from 18° C at Arica in the North to 6° C at Punta Arenas in the South. Maximums can reach 46° C in the Atacama Desert.

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HYDROGEOGRAPHY

Water Resources

Chile's total land area of 756,950 km^2 is about 1% freshwater, amounting to a total volume of 922 km^3. Of Chiles's total renewable water resource, groundwater accounts for 15%, and surface water 85% (FAO 2001). About 15% is shared between the two resources. There are no flows into Chile from other countries and the only outflows are to the Pacific Ocean. Groundwater withdrawals total 20.3 km^3 annually, or about 15% of the actual annual groundwater recharge (140 km^3). Most of these withdrawals are for mining in the North and agriculture in Central Chile. These figures don't tell the whole story since the groundwater withdrawals are in the arid North with low recharge rates. Surface water withdrawals are currently mainly for agriculture irrigation (64%). Although domestic uses of total surface water is low (11%), the presence of most of the population in the Mediterranean climate of the Central zone places a lot of stress on local water resources.

Water is a scarce commodity from the Rio Bío-Bío northward (Wollman 1968). This is virtually the northern half of the country, including the major metropolitan areas of Santiago, Valparaiso, and Concepcíon. Water supplies in the Central and South zones are predominantly surface in nature, originating in snow and glacier melt in the Andes. In the North, high evaporation rates of the Atacama Desert consume most rainfall and the limited surface

Table 1. Average annual precipitation by major city and region, Chile (CIA 2008, FAO 2001).

CITY	AVERAGE ANNUAL PRECIPITATION	LOCATION	REGION
	mm		
Arica	<1	North	Arica
Copiapó	21	North	Atacama
Santiago	330	Central	Santiago
Concepcion	1320	Central	Bío-Bío
Valdivia	2535	South	Los Rios
Puerto Aisén	2973	South	Aisén
Chiloé National Park	>4000	South	Los Lagos

waters, leaving dry riverbeds or large salt playas. Groundwater is the most important water source in this region.

Rivers and Lakes

Rivers in Chile are relatively short, flowing from the Andes crest westward to the Pacific Ocean. Few rivers in the North flow to the sea because of high evaporation rates and much diminished precipitation (Table 2). Their main source is Andean snowfall and rain. In the North, the Rio Loa is the only river between Arica on the northern border with Peru and the Rio Copiapó (960 km) that flows to the sea. It reaches the Pacific with very diminished flows (mean flow 2.4 m^3/sec) despite having a large drainage basin (33,570 km^2) and reasonable length (440 km). South of the Rio Copiapó and the Rio Huasco in the Atacama Region, the number of rivers that flow continually to the sea increase dramatically (e.g. Elqui, Limari, Maipo, Rapel, Mataquito, Maule, Itata, Bío-Bío, Imperial, Tolten, Palena, Baker etc.). Rivers such as the BioBío are being developed with dams for hydroelectric and water supply purposes.

Most of the lakes in Chile are in the Araucania Region and South (Table 2). There are 17 lakes with areas >100 km^2. The largest is General Carrera Lake covering 1,850 km^2 with half in Chile and the remainder in Argentina. Two are in the 500 to 1,000 km^2 size class, five are 200 to 500 km^2 in size, and the remainder 100 to 200 km^2 category (Wollman 1968).

There are a number of water supply and power generation reservoirs throughout Chile, mainly in the Central and South regions. For example, El Yeso is a reservoir located in the Andes formed by damming the Rio Yeso, a tributary of the Rio Maipo. The reservoir is located in tandem with Laguna Negra at an altitude above 2,600 m. It provides a storage capacity of 255 x 106 m ^{3}, or about 46.3 m^3/person for the Santiago Metropolitan Region.

WATER ISSUES AND USES

Land use

Most of the issues related to water center around land use and water availability. The major issues deal with population concentration in the Santiago Metropolitan area (33% of Chile's population), agriculture, mining, dam construction for hydroelectric generation, and climate change. The latter interacts with the other land uses and activities. Currently land use in Chile is 3% in arable crops, 16% in meadows and pastures, 21% in forests and woodlands, and 60% in other categories, mostly desert and high mountain lands (CIA 2008). The great disparity in water resource abundance between the arid North and wet South also aggravates the internal water resource situation. Mining in the North and population concentration in the Santiago Region, although separated by great distances from the water rich South are affecting decisions on how to use those water resources.

Agriculture

Agriculture is a key part of the economic mix of minerals, food commodities wood products, and fishing that has been the base of the Chilean economy. Agriculture accounts for only 5% of the

Table 2. Main rivers and lakes by Region of Chile (Wollman 1968, CIA 2008, FAO 2001).

REGION	RIVERS	LAKES
Arica and Parinacota	4	1
Tarapacá	0	1
Antofagasta	4	3
Atacama	7	1
Coquimbo	6	1
Santiago	6	1
Valparaiso	7	2
O'Higgins	3	1
Maule	20	0
Bío-Bío	22	1
Araucania	26	7
Los Rios	25	7
Los Lagos	10	11
Aisén	10	3
Magallanes	11	10

country Gross Domestic Product but employs 14% of the national labor force (CIA 2008). Chilean crop products are becoming increasingly important internationally because of their availability during northern hemisphere winter and freedom diseases affecting other nations. Chile produces 3.9 x 10^6 Mg of fruit, 1.2 x 10^6 Mg of wheat, 0.5 x 10^6 Mg of sugar, and various amounts of vegetables, beef, poultry, and wool. However, 96% of the agricultural lands are irrigated from surface and groundwater supplies (>12,650 km^2). Water flowing out of the Andes Mountains is critical for Chilean agriculture. Thus the recent droughts related to climate change are a big issue since increasingly scarce surface waters have to be reallocated amongst competing economic sectors, including human water supply demands.

Hydroelectric Power

Chile's electric power generation capacity is now highly dependent on water resources in the South. The national energy grid (SIC) has been fragile because of its dependence on water resources. Chile has not been able to keep up with energy demands from the public and mining sectors so that its generation capacity of 48 x 10^9 kWh has to be constantly supplemented (CIA 2008). For awhile Argentine natural gas was supplementing electric power production until rising prices and a restriction on exporting Argentine natural gas forced a switch to diesel fuel for thermoelectric power plants, raising costs four-fold in 2008 (Reuters 2008). Chile currently supplies about 60% of its electrical energy from water (Business News America 2008). Plans have been developed to build five hydroelectric dams on the Rios Pascua, Baker, Del Salto, and Bío-Bío at a cost of $2.4 billion to provide an additional 2,430 Mw of power production capacity. New transmission lines will be needed to move the hydroelectric energy over 3,000 km north to the population and mining centers. However, the scale of this project along with dam placement on ecologically important rivers in the South has created considerable internal political dissent (New York Times 2008). Nevertheless, energy demands keep rising and unless conservation measures reduce demand, Chile will have to add 300 Mw.

Mining

Mining has a major effect on the water resources of Chile because large quantities are needed for ore processing. In addition, smelting is a big consumer of electrical energy. For instance, daily use of water in the mining and processing stages at El Salvador is 65×10^3 m^3/day (2.5 m^3 of water per ton of ore processed). The source of this water is groundwater since the mine is in the Atacama Desert.

CLIMATE CHANGE EFFECTS

The effect of the El Niño/Southern Oscillation on Chilean weather has been well documented (Nuñez 1992; Haylock et al. 2006). Long-term trends investigated by Minetti (1998) documented a steady decrease in annual rainfall for a large area west of the Andes Mountains under La Niña conditions. Rusticucci and Penalba (2000) described a large decrease in total annual precipitation at Valdivia in the Los Rios Region (Table 1) due to a decrease in winter precipitation. Winter snowpacks observed by the authors in mid-August, 2007, at elevations above 2,000 m were shockingly low. North-facing areas at >3,000 m that should have been entirely snow-covered in August were devoid of snow. These trends have been evident in extreme southern Chile where glacial melt rates are some of the fastest in the world and account for nearly 10% of global sea level change from mountain glacier melt. Some Andean glaciers are expected to disappear in 15-25 years (Vidal 2006). The effects will be major, reducing municipal water supplies and agricultural irrigation sources. However many effects are occurring now, not in the future. The current La Niña Began in May, 2007, and is expected to end in August, 2008 (Estrada 2008). It has been atypical in that areas such as Araucania, which normally get heavier rainfall in a La Niña, have been experiencing drought as well.

In March, 2008, Chile's Public Works Ministry Undersecretary J.E. Saldivia described the current drought as the worst in 100 years, threatening water supplies for over 200,000 people (Vargas et al, 2008). He stated that the drought was intensifying, and that even if rainfall improves this year, the resulting hydroelectric energy shortage could become critical. Chile's major hydroelectric reservoir levels are far below their historic levels, and will need at least one year to rise to normal levels even if this year's rainfall is normal. Mr. Saldivia was quoted as saying that "*reservoir levels will not recover normal levels and that means (crop) irrigation in 2008-2009 will be difficult*." Rainfall deficits have been in the 35 to 100% range from Arica in the North all the way south into the Bío-Bío and Aisén regions of the far South. Shallow wells supplying many small towns and farms have dried up.

Agricultural production in Chile this year has been seriously affected by both the shortage of water and the high cost of pumping groundwater for irrigation (Vargas 2008). Fresh produce production has declined significantly and animal forage is in short supply. Drying up of shallow groundwater wells (6 – 10 m) has resulted in significant animal mortality (Martinez 2008). Fruit growers have not been impacted yet due to their deep wells (>50 m). Over 144 municipalities have declared agricultural emergencies because of the current drought (Estrada 2008). There are indications that the current year-long La Niña droughts may become due to the Pacific Decadal Oscillation (Mantua and Hare 2002). So, agricultural impacts could be much greater in years to come.

Agriculture has already been impacted by power costs and shortages (Vargas et al. 2008). President Bachelet ordered voltage reductions during the Chilean summer of 2008 and extended daylight savings time. Also ominous is the potential threat to mining, a mainstay of the Chilean economy and a large consumer of power. In March, hydroelectric reservoirs were dangerously low. Energy supplies will remain uncertain until 2010 when more hydroelectric production comes on line from current dam and power line construction in the southern areas of Chile. At a time when prices for minerals such as copper are rising due to world-wide demand, prices could rise much higher if Chilean production is significantly reduced by the lack of hydroelectric power.

SUMMARY

Chile has a tremendous diversity of water resources as a result of its geographical position in South America. It contains both the driest desert in the world and one of the wettest regions. The country is highly dependent on Andes Mountains annual snowpacks and glaciers for water used for municipal, agricultural and mining activities. In addition, a large portion of the Chilean energy market so important for cities, agriculture, and mining comes from hydroelectric sources that are also subject to the oscillations in climate. The current La Niña is abnormally dry across the entire 4,300 km of Chile. This ENSO event may be a harbinger of droughts to come as global climate change becomes more pervasive. Recent understanding of the Pacific Decadal Oscillation (Mantua and Hare 2002) indicates that future droughts could be on the order of decades-long durations rather than 1- to 2-years. Impacts on the major water-using sectors of the Chilean and global economy could be significant.

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