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ASSESSING THE NEEDS OF USERS OF WARM SEASON QUANTITATIVE PRECIPITATION FORECASTS IN COLORADO

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1. INTRODUCTION

Recently, the U.S. National Weather Service and the U.S. Weather Research Program have identified improving quantitative precipitation forecasts (QPFs) as a major goal during the next 5-10 years (NWS 1999, USWRP 2001). The emphasis on improving QPFs was motivated in part by a general understanding of the importance of precipitation-related information to society, in areas such as flood forecasting, water resource management, and agriculture. However, QPFs can be improved in a number of ways, and different types of improvements are likely to lead to different benefits. Furthermore, achieving different QPF improvements can require different research and operational efforts.

To provide additional information about which improvements in QPFs are likely to benefit society the most, this study is performing an in-depth assessment of the needs of users of QPFs in the warm season (approximately May through September) along the Colorado Front Range (loosely defined in this study as Denver, Boulder, Fort Collins, Colorado Springs, and nearby areas in the mountains, foothills, and plains). The forecast lead times considered range from several minutes (nowcasts) to approximately two weeks; longer-term forecasts are not included.

Although limiting the study to the use of forecasts during the warm season in a specific region limits the applicability of the results, such a focus was necessary to allow a detailed, complete assessment. The focus on the warm season was selected because the study was initiated as part of a study of meteorological verification methods for warm season QPFs. The focus on the Colorado Front Range was selected in part for its proximity to the researchers' institutions, so that new users could be interviewed as they are identified (important for this pilot study). This region was also selected because it is reasonably geographically, demographically, and economically diverse, and thus includes a variety of precipitation-related impacts on society and a variety of users of QPFs.

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In order to obtain a detailed, complete picture of how QPFs are used, information is being collected and synthesized from a number of sources produced from a range of perspectives. These include: 1) meteorology, hydrology, and other relevant literature; 2) interviews with stakeholders, including providers of QPFs, users of QPFs, and intermediaries; and 3) a survey of selected user communities. The study is still in progress; much of the literature review but only a few interviews have been completed. All of the ideas presented and discussed are therefore preliminary.

In section 2, the methodology for the study is described in greater detail. Section 3 discusses the major sectors of potential users of QPF that have been identified thus far. Section 4 divides these users into two categories, then briefly describes the QPF-related needs of users in each category. The final section summarizes. Despite this study's focus on a specific region and type of forecast, some of the results are likely to be relevant to other regions and types of forecasts. Furthermore, similar assessments could be implemented to examine the needs of users of other types of forecasts, in other regions, or in specific sectors, or some combination of the above.

2. METHODOLOGY

The first step in the study is to identify the major users and uses of QPFs. An initial list of potential users was constructed from a variety of sources, including web searches, National Weather Service documents, studies of users of weather and climate information, and conversations with researchers and forecasters. This initial list was used to proceed to subsequent stages of the study; as additional information about users of QPFs is gathered, however, the list will continue to be revised.

The second step is to review and synthesize relevant literature to develop, for each of the user sectors identified, baseline knowledge of how precipitation affects the sector and how QPFs are and might be used. The literature incorporated includes: overview documents; studies of use of weather and climate information; information about public and private organizations in each sector; peer-reviewed literature in meteorology, hydrology, and other relevant subjects; instructional materials; conference proceedings; and a variety of other sources. Obviously, only a small fraction of the potentially relevant literature in each sector can be included. However, given that the goal of this step is primarily to develop sufficient knowledge to implement the next step, i.e., to identify an appropriate mix of users to interview and construct appropriate interview questions, the strategy adopted was to read about each sector until most of the information gathered was redundant. As the study proceeds and new important literature is identified, it will be incorporated into the results.

The third step is to interview several stakeholders, i.e., people or groups of people that can affect the outcome of the use of QPFs or have a need or capacity to use QPFs (Benequista and James 1999), in each sector. The first set of interviews is with providers of QPFs, including personnel in the two National Weather Service forecast offices in the region (Denver/Boulder and Pueblo), the Missouri River Basin River Forecast Center, the Hydrometeorological Prediction Center, and at least one private company that provides QPFs. The second set of interviews is with personnel in organizations that serve as intermediaries between QPFs and users, e.g., the River Systems and Meteorology Group at the U.S. Bureau of Reclamation and agricultural extension services. The third set of interviews is with individual users of QPFs, e.g., flood warning personnel, or representatives from groups of users, e.g., farming associations, in each sector. The interviews are divided into three sets and conducted (to the extent possible) in this order so that information from each set can be used to help identify individuals to contact and refine questions for subsequent interviews.

The information gathered from the interviews will be analyzed to construct a more complete, more detailed understanding of how QPFs are and could be used in each sector than is possible from a literature review. Each set of interviews can also be used to test and (if necessary) modify hypotheses and knowledge developed earlier in the study. Note that the purpose of the interviews is not to gather information from a statistically representative sample in each sector, but rather to learn in more detail about the range of current and potential uses of QPFs. Thus, in selecting interviewees and asking questions we focus not on statistical sampling, but on ensuring that a range of perspectives is represented.

In one or more sectors, the literature review and interviews may suggest that more detailed information about QPF use is required from a wider range of individuals than can efficiently be interviewed. In this case, a mail and/or e-mail survey of users in these sectors will be conducted to complement the information already collected and fill in gaps.

3. SECTORS OF POTENTIAL QPF USERS

Table 1 lists the potential users of warm-season QPFs along the Colorado Front Range that we have currently identified for further investigation. In several of these sectors, such as flash flood warning, use of QPFs is prevalent. In other sectors, such as livestock production, use of QPFs (on 0-14 day time scales) is much more limited. All of the sectors on the list, however, are included because initial exploration suggests that they satisfy two important criteria for potential users: 1) precipitation-related events can cause damage or affect activities in the sector; and 2) people in the sector may have the capacity to make some decision, based in part on information about future precipitation, that might mitigate this damage or improve management of these activities.

In the warm season, precipitation falls as rain, and the major hazard from large amounts of precipitation is flooding. People who must warn and evacuate those at risk from flooding and/or coordinate the response to a flood as it occurs, e.g., emergency management personnel, can use forecasts of precipitation to prepare or react with greater lead time, and thus are a major user of QPFs. Flood control personnel, e.g., managers of storm drainage systems, can also use QPFs to help mitigate the negative effects of major precipitation events. Large amounts of precipitation can also saturate soil, leading to landslides in mountainous areas. Thus, QPFs can assist in assessing landslide risk, providing additional lead time for warning, control, and response. These two precipitation-related hazards, floods and landslides, are listed together in Table 1.

Managers of water reservoirs are faced with multiple (often competing) demands for limited water supplies, particularly in a semi-arid region such as Colorado. These demands include: water supply for irrigation and domestic, commercial, and industrial use; flood control, i.e., allocating a portion of the reservoir volume to store water that could otherwise cause a flood downstream; water storage and flow for generating hydropower and for cooling power plants; water level in the reservoir for recreation; and in-stream flow requirements for ecosystem maintenance and restoration, navigation, recreation, water quality, and intergovernmental agreements. Suppliers of water must not only provide the required volume of water, but also maintain water quality, which can be affected by insufficient flow to dilute undesired materials (e.g., salt and pollutants) or by precipitation that washes large quantities pollutants, soil, and other contaminants into the supply. QPFs can help provide these users with water inflow and demand forecasts that are more skillful or available further in advance, helping them meet delivery targets and better manage resources. Thus, water supply and reservoir management and power generation are additional sectors that could use QPFs.

In the construction industry, precipitation can cause damage during or limit a variety of activities, ranging from remodeling projects that require removing part of a roof to concrete pouring. QPFs can therefore help managers of construction projects and companies make decisions that mitigate damage and more efficiently schedule activities

TABLE 1. Preliminary List of Potential QPF Users in Colorado

User Sector	Category
Flood / landslide warning, control, and response	Detailed-amount
Water supply and reservoir management	"
Hydropower generation and power plant cooling	"
Construction	General-amount
Transportation	"
Mining	"
Fire management	"
Agriculture	"
Livestock production	"
Recreation / leisure	"
Public	"

and staffing. In transportation, heavy precipitation can disrupt air and land transport, and unusually high or low river flows caused (in part) by high or low precipitation can disrupt river transport. In mining, precipitation can also disrupt activities, and in fire management, precipitation or lack thereof can affect whether controlled burns and wildfires burn out or burn out of control. Thus, in these sectors, QPFs have potential to assist decision-makers in mitigating damage and in planning.

In agriculture, precipitation affects the success of sowing and harvesting, the amount of irrigation required, the prevalence of pests, and the effectiveness of fertilizer and pesticide applications. Livestock production is also affected by precipitation, through effects such as the availability of natural vegetation for grazing on rangelands. In recreation and leisure, precipitation can affect activities ranging from attendance at an amusement park to the postponement or cancellation of an outdoor sports event. And, of course, precipitation affects the general public in ways not included in the other sectors, such as when one leaves windows open or is on a bicycle ride when it rains. In all of these areas, therefore, precipitation forecasts have potential to help people make decisions that mitigate harm or improve management of resources.

4. CATEGORIES OF QPF USERS

Based on the literature review, we have divided the QPF users listed in Table 1 into two categories. The first category, called "detailed-amount" users, includes those users who, at least in some situations, desire high-resolution information about the amount of precipitation that is expected to fall, in other words, who might make a very different decision if 1.1 inches of rain is forecast than if 1 inch of rain is forecast. The second category, called "general-amount" users, includes those users who desire only general information about the amount of precipitation that is expected to fall, in other words, who might make a different decision if 1 inch of rain is forecast than if 0.1 inch of rain is forecast, but cannot or do not differentiate between the effects of 1 inch and 1.1 inch of rain. Note that these categories relate only to the resolution in the amount of precipitation that users desire, not to the spatial or temporal resolution in the information.

Information gathered so far suggests that flood warning, control, and response, water supply and reservoir management, and power generation are in the detailed-amount category, and the remaining user sectors listed in Table 1 are in the general-amount category. The remainder of this section discusses preliminary findings on the QPF-related needs of users in each of the categories, beginning with the general-amount users.

4.1 *Users of general information about precipitation amounts*

Users in this category tend to make decisions based on the perceived risk of surpassing some threshold in precipitation amount, intensity, and/or duration. In the recreation sector, for example, a manager might choose to postpone or cancel an outdoor baseball game if the amount of precipitation during a certain period of time, the precipitation intensity, or the duration of precipitation is or is expected to be sufficiently high to have an undesirable negative effect on the field, the players, or the fans. Because users in this category generally cannot distinguish among the effects when the precipitation increases or decreases a small amount near this threshold, the thresholds tend to be approximate. In other words, users will take action when there is "a lot" of precipitation according to their definition, but not when there is "a little bit" of precipitation — and thus they do not generally require high precision or accuracy in the precipitation amount.

Because users in this category tend to be concerned primarily with whether a lot or a little bit of precipitation is likely, they may, according to some definitions of QPF, be considered users of qualitative precipitation forecasts rather than QPFs. However, the threshold used to decide whether there is a lot or a little bit of precipitation depends on the application, on the characteristics of the individual user (such as risk tolerance), and often on the characteristics of the specific situation. Thus, if the many applications in the different sectors are integrated, they form a mosaic of thresholds that together indicate a general need for QPFs.

Although users in this category tend to require fairly low-resolution information about the amount of precipitation likely to fall, the resolution that they desire in other aspects of QPF information is often quite high. Most users in this category, for example, are concerned about precipitation at specific locations (or in the transportation sector, along specific routes). Thus, they desire precipitation forecasts with high spatial resolution. In some cases, when the activities at risk from precipitation take place only at specific times of day, they also desire high temporal resolution forecasts. In general, therefore, the spatial and temporal averaging in current QPFs makes them undesirable or, in some cases, unusable for many potential users in this category.

Note that users in this category often appear to make "yes-no" decisions based on thresholds, as users do in a simple "cost-loss ratio" model. However, many of these users make decisions not at a single time, but continuously, as new information becomes available. In the baseball game example above, for example, the manager is likely to make a continuous series of decisions about whether to continue with the game as scheduled or institute a delay, and once he or she has stopped the game, to make a continuous series of decisions about whether to restart it or continue the postponement. Only when the game has been cancelled does the decision-making stop (at least for that particular decision). Thus, many of the users in this category cannot be modeled using the single decision, cost-loss ratio method.

4.2 *Users of detailed information about precipitation amounts*

The users in this category (flood warning, control, and response, water supply and reservoir management, and power generation) are concerned about precipitation primarily through its effect on streamflow. Thus, their QPF-related needs are closely connected with how precipitation is transformed into streamflow through the system of catchments (watersheds) and channels. How precipitation is transformed into streamflow depends on a number of characteristics of the catchments where the precipitation falls, including their size, slope, and surface and soil properties. The streamflow information that users desire also depends on the societal characteristics of the catchment of interest, such as where people, property, and transportation routes are vulnerable to flooding or the advance notice required to take different actions. The precipitation information desired therefore depends on both the physical and societal characteristics of the system. Consequently, which aspects of QPFs (what lead times, what temporal and spatial resolutions, and so on) are most important to users in this sector varies significantly from location to location and situation to situation.

Despite the variability of user needs, there are several general statements that can be made about which information in QPFs is most important to these users. First, given a specific catchment with certain physical and societal characteristics, the most important factor affecting how much streamflow results from precipitation is the amount of precipitation falling in the catchment during a certain period of time. Thus, to first order, users in this sector require QPFs distributed on spatial scales that are at least as small as the catchment of interest (whose size depends on the situation). Second, the proportion of precipitation that runs off directly instead of soaking into the ground depends on both the physical characteristics of the surface (including how saturated the soil is due to recent precipitation) and the precipitation intensity. Thus, users can also be interested in the timing of precipitation in a QPF, particularly how much of the precipitation is likely to fall in intense bursts. In some situations, more detailed information about the spatial and temporal distribution of precipitation can also be important, but only after QPFs have provided the first two types of information.

5. SUMMARY

The purpose of this study is to provide additional information about which improvements in QPFs are likely to most benefit society by performing an in-depth assessment of the needs of users of warm season QPFs along the Colorado Front Range. The assessment consists of an effort to identify all major sectors of QPF users in the region, followed by a basic literature review in each sector, interviews with QPF providers and users, and in some sectors, a user survey. By gathering and synthesizing information from a variety of sources and perspectives, we hope to construct a comprehensive picture of which aspects of QPFs are most important for the forecasts to benefit society in a range of activities across the U.S.

Initially, we have identified approximately 10 sectors of users, listed in Table 1. Information gathered so far suggests that these sectors can be divided into two categories: users who desire detailed information about the amount of precipitation that is likely to fall, and users who desire general information about precipitation amounts. Users in the second category are often more concerned with spatial (and in some cases temporal) detail in QPFs than with the specific precipitation amount. Users in the first category are mainly concerned with precipitation to the extent that it is translated into streamflow; consequently, for them, the most important attributes of QPFs are the amount of precipitation falling in the catchment of interest over a certain period of time and the intensity of precipitation. Since the study is only partially completed, this analysis is based primarily on literature reviews and preliminary interviews; further study is still needed to test, modify, and augment these ideas.

REFERENCES

Benequista, N., and J. Schrag James, 1999: Pilot stakeholder assessment report. Climate Assessment for the Southwest, Institute for the Study of Planet Earth. Available from http://www.ispe.arizona.edu/climas/-pubs/stakeholder/index.html.

National Weather Service, 1999: The modernized end-to-end forecast process for quantitative precipitation information: Hydrometeorological requirements, scientific issues, and service concepts. National Oceanic and Atmospheric Administration, U.S. Department of Commerce, 187 pp.

U.S. Weather Research Program (USWRP), 2001: An implementation plan for research in quantitative precipitation forecasting and data assimilation. 55 pp. Available from http://box.mmm.ucar.edu/uswrp/-implementation/implementation.html.