River Forecast Centre Review

November 30, 2010

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1. Introduction

1.1 Background

The River Forecast Centre and Snow Survey Operations were reviewed in a "Business Review" in 2005. The review was completed in March of that year and significant government reorganization followed the election of May 2005, including the formation of the Water Stewardship Division in the newly recreated Ministry of Environment. The River Forecast Centre and Snow Survey Operations were located in The Science and Information Branch of the Water Stewardship Division along with oversight of the hydrometric program and other water information activities.

The 5 years between the summers of 2005 and 2010 witnessed interesting hydrologic times, with both flood and drought events. Progress was made on implementation of some of the recommendations of the 2005 report as reviewed below. In addition, the snow survey data functions were separated from the River Forecast Centre and the total personnel available for this function was reduced.

Two recent events precipitated this current review. Firstly, the Head of the Forecast Centre has left for new employment. This has caused a review of the job description and a posting for a new employee - always a good time to review the functions of the organization. Secondly, the Ministry of Environment is undergoing another reorganization that has placed the Science and Information Branch in a newly-named Knowledge Management Branch with an expanded mandate. The Director of the Knowledge Management Branch has contracted this review to "conduct a water supply and river forecast function business review and provide a risk assessment of the water supply and river forecast function".

Subsequent to the commencement of this contract, the natural resource operations of government were reorganized and the contractor was asked to advise on the "best fit" of the River Forecast Centre into the new structure of government.

1.2 Brief History of River Forecast Centre

The three largest floods recorded on the Fraser River occurred in 1894, 1948 and 1972. After the devastating 1948 flood, which caused inundation of major parts of the Fraser Valley as well as several interior BC valleys, a group was created in the provincial government to regularly measure snowpack to give some indication of the flood potential in the coming year. Snowpacks have been measured continuously in BC since the early 1950s.

In February of 1972, the snow surveys indicated an above average snowpack. Subsequent surveys continued to report "heavy mountain snowpacks". By mid-March, the provincial government alerted the Civil Defense Units of the possibility of flooding on the Fraser River and in mid-April, meetings were held to coordinate the response of agencies that would be involved. Flood damage occurred in Prince George, Kamloops, parts of the Fraser Valley and Surrey. In the aftermath of this event, a flood forecast group was created to provide advance notice of potential flood events. This group, initially called the "Flood Forecast Centre" has for the last two decades been known as the River Forecast Centre.

1.3 Previous Review

On March 31, 2005, Water Management Consultants Inc. presented a report to the then Ministry of Water, Land and Air Protection called *River Forecast and Snow Surveys Business Review*. The report was a joint product primarily prepared by C. David Sellars, P. Eng. of Water Management Consultants (now part of Schlumberger Water Services) and John Azar of Azar & Associates/Canopy Management Group. That report is referenced throughout this study as the "2005 Business Review".

That study clarified the purpose and objectives of the River Forecast and Snow Surveys functions, assessed the ability of the program to deliver the objectives, identified the elements required to sustain the operation, and then looked at the whole process from a "systems" perspective. This approach allowed an assessment of critical gaps and unnecessary overlaps to the efficient flow of critical information.

Although the Executive Summary does briefly state the major conclusions and describes "urgent needs" and "priorities" as well as options that "should be evaluated" and "opportunities that have been identified", there is no action plan nor any itemized list of recommendations or actions that would make it easy to fill the gaps or take advantage of the opportunities. This lack of recommendations or an action plan also makes it difficult to assess progress since the report was written.

A discussion with David Sellars, principal author of the report has revealed that their contract required them to stop after the analysis and conclusions. The Ministry intended to decide what action they planned to take and intended to write their own action plan but never did, probably due to the reorganization that occurred a few months after the report was completed.

Identified actions from the 2005 Business Review and a discussion of their status is done throughout Section 3 in the description of River Forecast Centre operations.

1.4 Scope of Work for this Review

This review is restricted to the River Forecast Centre (RFC) and does not include any review of the necessary input functions that support the forecast operations such as snow surveys or the hydrometric program. Specifically, the scope is limited to:

- Focusing on the business of the RFC and describing that business;
- Identifying the risk inherent in the current model of operation, qualitatively if not quantitatively;
- Identifying gaps in operations that may be exacerbating the risk;
- Identifying opportunities and describing benefits; and
- Recommending changes or improvements where appropriate.

1.5 Methodology

This review began by clarifying the purpose and objectives of the River Forecast Centre in an informal workshop session with staff of RFC to determine what they thought their objectives were, where they saw risks, and who they identified as their clients. Following this workshop, interviews were held with individual staff of the RFC.

The forecasting program was then reviewed looking at the major components, including legislative and program foundation, forecast inputs, process and products. This allowed a full description of the RFC operations.

Interviews were conducted with a small selected sample of major clients, including regional water managers, directors, selected local government representatives and the members of Emergency Management BC. These interviews solicited client opinion on the purpose and objectives of the RFC and value of the forecasts to each client. The great reliance of users on these forecasts and the wide uses to which the forecasts are put became quickly apparent.

A risk analysis defined performance measures for the RFC and assessed the sources of risk to achieving the RFC objectives. For the purposes of this report, the author has looked at the concept of "adequate and timely" advice and sought to identify the sources of risk that would prevent advice from being adequate and timely as well as the trends and priority of these risks. Finally, risk mitigation recommendations are made.

Future casting was done to the extent of looking at growth and development forecasts for British Columbia and trends in climate change that may affect RFC objectives or operations.

Options for program delivery were examined in light of the major reorganization that is underway on the natural resource management side of government.

Throughout the report, conclusions are highlighted in bold font. Recommendations are numbered consecutively and are repeated at the end of the report.

2. River Forecast Centre Overview

2.1 Legislation

The Emergency Program Management Regulation (under the *Emergency Program Act*) sets out the method of operation for response to provincial emergencies and provides authority for the Provincial Emergency Program.

Schedule 1 of the Emergency Program Management Regulation sets out the responsibilities of the Ministries. The Ministry of Attorney General (MAG) is responsible for coordinating the response to most "Atmospheric" hazards such as tornados and wind, snow or ice storms. "Hydrologic" hazards of drought and storm surges are also the responsibility of MAG. The Ministry of Transportation leads for flooding and ice jams, while the Ministry of Environment leads for erosion and accretion, submarine slides and dam failure. Work was done to amend these ministerial responsibilities in 2008 but it appears not to have been completed. Recent discussions with EMBC indicate that it is being redone again in light of the government reorganization on the natural resource side.

Under the current schedule 2 of the Emergency Program Management Regulation, the Ministry of Environment is required to (among other things):

- provide flood forecasts and bulletins;
- provide flood assessment, technical services and planning staff at government operation centres in the case of floods;
- provide dam safety and inspection services.

The British Columbia Flood Plan (BC Flood Plan), describes the concept of operations for responding to and managing a flood hazard event and its consequences. The plan is a living document that represents an agreement between various ministries and agencies of the provincial government. The most recent version is dated 2007 and was signed by representatives of the four primary ministries involved in flood support: the Head of the Provincial Emergency Program of the Ministry of Public Safety and Solicitor General, the ADM of the Water Stewardship Division of the Ministry of Environment, the Chief Engineer of the Ministry of Transportation, and the Executive Director of the Public Affairs Bureau.

Under the BC Flood Plan, the Ministry of Environment provides expertise and resources, as required. This may be in the form of flood forecasting, assessment, technical services and planning. In addition, ministry representatives may staff the Provincial Regional Emergency Operations Centres, Provincial Emergency Coordination Centre or local Emergency Operations Centre(s). A senior MOE member participates as a member of the Central Coordination Group. The River Forecast Centre provides flood forecasts and bulletins as necessary through the spring and fall flood window and provides special reports daily, and sometimes every few hours during flood events.

2.2 Mandate and Objectives

To properly review the operations of the River Forecast Centre, it is necessary to clearly identify what objectives the Centre is trying to achieve. There are no published performance objectives that could be used to define success or measure performance. Discussions with staff including forecasters, the RFC Manager, the Branch Director (in place since 2005) and with the former Head of the RFC who has recently left for another position determined that the primary focus of the RFC is public safety from flooding. The key responsibilities identified were:

- accurate and timely forecasts to enable local and provincial governments to respond to act to avoid loss of human life and to take steps to minimize property damage; and
- accurate and timely information during flood events to assist in flood response management.

For the purposes of this study:

Accurate is defined as forecasted flows and levels that cause a response that neither overreacts (evacuating people unnecessarily or spending excessive amounts of money taking urgent actions that were unneeded) nor fails to react sufficiently (leaving people exposed to flooding or allowing preventable damage).

Timely means sufficient notice is given of an impending event that there is enough time to take the appropriate response.

These objectives and performance measures were then tested during interviews with staff from Emergency Management BC and local government clients.

2.3 RFC Clients

In discussions with the staff of the RFC, three sets of primary sets of clients emerged: (1) Ministry of Environment staff, (2) Emergency Management BC , and other government staff, local and First Nations government and other first responders, and (3) the general public including the media. This listing is in ranked order indicating the order of priority in which the information is disseminated and also reflects the degree of interaction and amount of information that is given out.

- *Ministry of Environment staff*

The primary clients of the RFC forecasters are the Regional Managers with water responsibilities (called here for simplicity "water managers"). Water managers are often contacted before any flood advisory is disseminated. RFC forecasters will often discuss with the water managers approaching storms, storm tracks, and timing and will sometimes seek information about the state of streams and the antecedent conditions of soil moisture, etc. Water managers use information on approaching storms for planning purposes, ensuring staff availability through a vacation period or for call out on a weekend for example. Once a flood warning is given, water managers may take some early action such as inspecting dams in the potentially affected area or deploying staff, as well as making sure that emergency contacts in their region have received the information.

Other Ministry of Environment staff that are advised early are the Regional Directors, the water program directors and the director with responsibility for the RFC. depending on the level of the alert, Assistant Deputy Ministers, the Deputy Minister or the Minister might be advised, although this information will generally flow through the directors. If there is a flood risk in an area that contains a Provincial Park, staff of BC Parks are also contacted.

- *Emergency Management BC (EMBC), Local and First Nations government staff*

If any significant event is forecasted, EMBC is advised. EMBC is the second most important client group and, for larger events, takes precedence over Ministry staff. Local governments and First Nations governments are the first responders for local flooding and they are notified by EMBC of any flood advisory. In addition, many local government staff and staff of First Nation governments are on email lists and get electronic bulletins directly from the RFC and directly access RFC information from the website as soon as it is posted.

Other government clients include provincial Ministry of Transportation, Ministry of Agriculture, and Ministry of Aboriginal Relations and Reconciliation.

BC Hydro and other major dam owners are sometimes contacted if they can manage their storage to ameliorate a flood peak, although these are not often contacted directly by RFC staff but instead are contacted by water managers. Major dam operators sometimes call RFC staff for discussions about inflow forecasts to assist in flow regulation.

When drought forecasts are given, both provincial and federal fisheries agencies are contacted as well as the Ministry of Agriculture, the Ministry of Community, Sport and Cultural Development [formerly Municipal Affairs], and the Ministry of Aboriginal Relations and Reconciliation if First Nations may be affected.

In addition to the flood advisories that are given by the RFC staff, Emergency Management BC staff and local and First Nations governments, RCMP, Ministry of Transportation and other first responders benefit greatly from briefings from RFC forecasters with question and answer periods on conference calls as well from direct personal contact over the phone.

***Recommendation 1*: Staffing in the River Forecast Centre must be adequate to provide for briefings and selected one-on-one conversations with field staff who respond to the emergency events. Participation by RFC forecasters in briefings should be encouraged.**

- *Media and General Public*

The RFC generally proactively advises the media, and thus reaches the general public with advice about staying away from low-lying areas near rivers and exercising care around stream banks, which may become eroded and unstable due to high flows. Flood advisories and warnings are newsworthy and are generally broadcast shortly after they are released.

- Client Summary

The River Forecast Centre staff have a good understanding of the needs of their direct clients, the regional water managers and Emergency Management BC. They are also aware of and responsive to the media. However, they have very poor links to local or First Nations government clients and subsequently a poor understanding of the needs of these clients or the use that is put to their forecasts by these clients.

> Being able to speak with a forecaster is of great value. Their ability to interpret data at the last minute is so valuable for me to respond properly. Their accuracy is very good.
>
> *Steven Waugh*
> *Central Coast Regional District*

***Recommendation 2*: The Head of the River Forecast Centre should work with EMBC to gain a better understanding of the needs of this wider client base with a view to improving the content and value of the forecasts for local government and other first responders.**

3. RFC Operations

At its most basic level, the job of the staff of the River Forecast Centre is to take weather forecasts and combine them with antecedent conditions of snow pack, river levels, etc. and their knowledge of the rivers of BC and make an informed estimate of the upcoming river flows and levels. These forecasts are then transmitted to the clients of the RFC either directly, through Emergency Management BC or through the media.

3.1 Components

The main products of the River Forecast Centre are:

- Volume Runoff Forecasts.
- Snowmelt Flood Forecasts
- Flood Situation Reports
- Drought Indicators and Water Supply Conditions
- Communications and contributions to the web-based Snow Bulletin

Each of these is described below.

- Volume Runoff Forecasts

Forecasts for the upcoming snowmelt season are made routinely starting on February 1 and repeated again on the first of March, April, and May. In the past, they forecasted the total runoff from about 40 major river basins around the Province by estimating the volume runoff in millions of cubic meters as well as expressing a percent of normal from the forecast date until the end of September. The Operational Volume Runoff Forecast (OVRF) system was described in the 2005 business review and is repeated here:

> *The forecast system is based on multiple regression equations using the following predictor variables:*
>
> - *snow water equivalent for the forecast date;*
> - *fall precipitation (September to November);*
> - *Winter precipitation (for a specified period);*
> - *Baseflow (for a specified period).*
>
> *Stations in the basin are combined to provide an overall basin index for each predictor variable using arithmetic totals. The equations used have not been updated since they were originally developed in the 1980s except for the Okanagan Basin.*
>
> *The Operational Volume Runoff Forecast model is a FORTRAN program that runs on a desktop PC linked to a VAX computer. The VAX computer system is no longer supported internally to the [RFC] and is scheduled to be phased out of operation in the next few years.*

Since 2005, the RFC advises that:

> *The OVRF program used in 2005 is now redundant. It no longer functioned with the workstation refresh to Vista. As a result, new equations were developed in Excel spreadsheets, but only for [7] basins:*
>
> - *Okanagan*
> - *Similkameen*
> - *Thompson*

- *Fraser*
- *Skeena*
- *Nicola*
- *Cowichan*

This information is no longer published as part of the Snow Survey Bulletin, and is used for internal purposes only. [since August 2010]

The Volume Runoff Forecasts (VRF) were developed in the early 1980s to be the early warning of the potential for spring snowmelt flood events. While the snow surveys can indicate the relative size of the snowpack and give an indication of the runoff, the VRF are the first quantitative runoff flood assessments for the year. They also provide early warning of the potential for drought events. Discussions with regional water managers show that the VRF were not much used on Vancouver Island except as background information for planning for such purposes as staff deployment and vacation scheduling.

In the Southern Interior, the VRF are used for the Okanagan River System operations. The forecasts are used to position the lake levels for drawdown and snowmelt fill. Okanagan Lake needs a long lead time to vacate capacity to hold the expected snowmelt inflow without flooding. Therefore the VRF is critical to the Fish-Water Tool that is used for operational decision making on the River. The VRF are also used in determining the permitted level of storage on Osoyoos Lake by the International Osoyoos Lake Board of Control. The members of the Water Supply Association in the Southern Interior also use the VRF in managing irrigation water supply dams in a similar fashion.

In the Southern Interior, the VRF is used for dam operation as well on the Nicola Lake dam. In low flow years, the VRF allows for early communication with ranchers who irrigate with water from Nicola Lake. A high volume runoff forecast allows drawing down of the lake level to help prevent flood damage in the Town of Merritt downstream.

In the North, the VRF is used for planning and staff deployment as well as a communication tool with various local municipalities. The regional manager in the North says he has discussed the VRF with the staff at the engineering department in the City of Prince George, who also use it for planning purposes. The regional manager also says that he has accessed the VRF from the Snow Bulletin for previous years that had similar forecasts to see what runoff was actually generated in those years to help him prepare for what might happen in the current year. With the VRF no longer being published in the web-based Snow Bulletin, this information is harder to access and is not available to clients outside of the Ministry nor to the public.

The Director of Water Management Branch and Comptroller of Water Rights says he uses the VRF only indirectly on the allocation side for planning purposes and for allocating staff if the Forecasts indicate a low runoff year. However, he also uses it in his role at the Permanent Engineering Board for the Columbia River Treaty when reviewing Assured Operating Plans for dams on the Columbia River. As well, it is used by both government staff and staff of BC Hydro in making revenue forecasts for the over $400 million in water rental fees that BC Hydro pays the Province. Low reservoir inflow means lower generation and thus lower fees.

Incidentally, natural gas companies will sometime review the VRF because if the inflow forecasts to the reservoirs are predicted to be low, then more gas will be needed for power generation at thermal plants as this is the next best power option. This means natural gas prices will probably rise in the forecast period and this can influence decisions made at the gas company.

These forecasts are clearly important as an early warning for the coming runoff season and are used for planning and for managing staff to ensure the right people are available in the right places to respond to possible events. Volume Runoff Forecasts also influence or directly affect a wide range of operational decisions from managing reservoir levels and river flows to revenue forecasts to satisfying our international obligations.

The Volume Runoff Forecast was not published for 2010 and appears not to have been published since the summer of 2007, although the calculations were done for some of the 7 basins on which the model is working.

There is no question that the Volume Runoff Forecasts are valuable as an early warning throughout the Province and for certain important operational decision making.

***Recommendation 3*: At a minimum, the VRF for the current 7 rivers should be continued.**

***Recommendation 4*: Regional managers should be polled to see what additional forecasts are necessary for improved operations.**

***Recommendation 5*: VRF for at least the 7 current rivers should be made available to the public in the web-based Snow Bulletin.**

- Snowmelt Flood Forecasts

Snowmelt flood forecasting is primarily done for the Fraser River. As stated above in Section 1.2, the potential to use of snowmelt for flood forecasting for the Fraser River was recognized in 1972. The Flood Forecast Centre (as it was then called) used a watershed model created at the University of British Columbia, called the UBC Watershed Model, and developed it into a program called the Watershed and River Numerical System (WARNS) model, which contained custom-written code to alter the UBC model to better model snowmelt. This WARNS model is often referred to as the Fraser River Model.

The description of the snowmelt modeling from the 2005 Business review is repeated here:

> *In 2002, the windows version of the UBC Watershed Model was calibrated for the Fraser River basin. However, it was found that the model as applied does not represent late-season snowmelt adequately. Furthermore, the UBC Watershed Model does not allow the basin conditions to be updated to reflect recorded snowpack data in the spring. The model is started in the previous fall and snowpack is accumulated in the model based on precipitation and temperature records. As the precipitation and temperature data are often at low elevation stations and do not necessarily reflect basin-wide conditions, the modeled spring snowpack can be significantly different from recorded snowpack. The UBC Watershed Model as currently configured does not reflect the best data available at the onset of the freshet. The [RFC] therefore still relies on the WARNS model for forecasting the Fraser River.*

The RFC advises that the Fraser River flood forecasting system has been upgraded. The WARNS Model was reprogrammed from Fortran into the "C" language, and incorporated into the Modeling Toolbox of the Aquarius software. Improvements to the model include the addition of the Lillooet and Harrison sub-basins. Although it is now possible, the model has not been recalibrated with current data.

The UBC Watershed Model was dropped for forecasting on the Fraser River after 2007 due to the limitations outlined in the report. The limitations such as not being able to update the modeled snowpack with actual readings became readily apparent during the near-record snowpack leading up to the 2007 freshet.

The WARNS model is currently running on a stand-alone PC computer that is not part of the Provincial government network [2005 Business Review].

This is partially true but as t he Model is only available on an RFC-specific version of Aquarius,. However, it is loaded onto all RFC staff desktop computers and the RFC lap top. This allows the model to be run remotely from the RFC office if the office were inaccessible for some reason such as fire, civil unrest, pandemic, etc.

There is a functioning "Mike 11" water surface profile model for the lower Fraser River downstream of Hope. This software resides in the Surrey office and is operated from there. This hydraulic model is used not only for flood forecasting but also design work on the lower Fraser. Its use is explained below.

Flood management activities in the Lower Mainland depend on the forecast for the river levels in the lower Fraser River. The key level is the height of the gauge on the Fraser River at Mission. The WARNS model is used to forecast the flow (discharge) in the Fraser River at Hope. The Lillooet River discharge is added in and then the total discharge is used to calculate a forecast for the River level at Mission. There are two methods for converting the discharge to a river level. The quick way is to use the stage-discharge curve, which is a graphical plot of measured flows and levels over a wide range of flows. The discharge is looked up on the graph and the corresponding river level is read off. The other way to calculate the river level is to use the discharge as input to the Mike 11 Fraser River hydraulic model and calculate the river surface level. This model uses actual surveyed river cross-sections and calculates the river level at all of the sections. It can take several hours to complete the calculations.

Because of the rapid conversion allowed by use of the stage-discharge curve, this is the preferred method. However, the Fraser River at Mission is composed of fluvial sediments and the profile can erode or aggrade, changing the stage-discharge relationship. After any high flow event, the stage-discharge relationship needs to be checked. Ideally, the relationship should be measured during a high flow event but this can be a very difficult task. A bathymetric survey can determine if there is any change in the cross-section but this can be time consuming and expensive. The hydraulic model also depends on accurate river cross-sections and its value as a forecasting tool diminishes with time from the most recent survey.

> "Thousands of people in the Lower Mainland depend on the River Forecast Centre -- what these people do in the next hours literally hangs on what the RFC staff say."
> *Neil Peters, Ministry of Natural Resource Operations.*

With the size of the population at risk from flooding in lower Fraser Valley and the Metro Vancouver area, the Fraser River flood model (WARNS) has proven to be a valuable forecasting tool and, indeed, is the only tool available for estimating flows in the Fraser River.

***Recommendation 6*: Update the current Fraser River Model (the WARNS model) and recalibrate with new data.**

Model replacement is dealt with under model risk below.

The use of the gauge on the Fraser River at Mission as the key indicator for decision-making regarding flood response activities underlines the need to ensure that the cross-section profile is regularly updated and the stage-discharge relationship is kept current.

***Recommendation 7*: The gauge on the Fraser River at Mission must have a cross-section profile that is regularly updated and a stage-discharge relationship that is kept current.**

There are other rivers in BC than the Fraser River, although none with the importance of the Fraser River. Referring to the 2005 Business Review:

> *Snowmelt models have also been developed for other rivers in the Province using the UBC Watershed Model namely the Skeena River, Similkameen River, Lillooet River and Elk River. None of these models are as well developed as the Fraser River Model due to limited data and resources.*

A WARNS Model for the Skeena watershed has been further developed. It models flows for the Bulkley River at Quick and the Skeena River at Usk. It was run for the first time during the 2010 freshet. However, considerable effort into model validation and calibration is required to get it fully functional. Further, some snow survey sites in the Skeena basin were deactivated in 2010 but they are being considered for reactivation. There are also new hydrometric sites in the Skeena basin. To get a functioning Skeena model, a data review needs to be done, then all appropriate sources of data need to be incorporated into the model and finally the model needs calibration.

- Flood Situation Reports

Flooding can also occur from rainfall with or without a snowpack. In the interior of the Province, rainfall driven floods often occur in May or June when the rivers are already swollen from snowmelt and the rain is the driving force that pushes them out of their channels.

Rainfall floods generally occur on the BC coast in the late fall (October through December) when large Pacific frontal systems come onshore heavily loaded with moisture. Typically the snowpack that exists by this time has limited ability to absorb the rainfall and there is a very quick response in the coastal rivers, which often reach flood stage. The 2005 Business Review stated:

> *The [RFC] monitors rainfall conditions at real-time Data Collections Platforms and receives heavy rainfall warnings and forecasts provided by environment Canada. This information combined with real-time flow gauging stations at key locations enable the [RFC] to identify the potential for flood conditions.*
>
> *On some rivers, models have been set up by the [RFC] but because of the short response times of the basins during rainfall flood events, limited input data available and the uncertainties in the rainfall forecasts, the models are limited in their ability to provide accurate flow forecasts. They are therefore used to provide assessments for internal use rather than specific forecasts of flows and river levels for public dissemination.*

The RFC advises that there are no rainfall flood models set up in the RFC. RFC staff review weather forecasts, real-time water levels, rainfall data, and historical flood event data, and depend largely on forecaster experience for analysis and interpretation for forecasting during fall rainfall flood events. The staff refer to this as "grey forecasting".

The RFC issues flood advisories in an escalating or staged manner. Advisories are sent out by email to EMBC and to regional staff and are posted. The RFC use of the terms "Flood Advisory", a term not used in the BC Flood Plan when high water is present and there is a need to take care, and "Flood Watch" and "Flood Warning", which are consistent with the use of those terms in the BC Flood Plan. There is an intermediate step in the Flood Plan called "Flood Alert" that appears not to be used by the RFC. There is also a final stage in the Flood Plan called "Flood Order" that is used when the local field commanders consider there is a high probability of serious damage and mandatory evacuations may be ordered. This is not a decision that the RFC can make and they are correct not to use this term in their notices.

The RFC issues advisories for all areas of the Province for which there are real-time water level data available, including the northeast. An archive of advisories is available on the website.

Accurate forecasts rely heavily on knowledge of coastal river response to rainfall inputs that is held in the heads of a very few people (currently 2).

***Recommendation 8*: Cross training of staff and a succession plan for the forecasters is essential to provide for business continuity of RFC functions.**

There is also a critical reliance on the meteorological forecasts from the weather office of Environment Canada. A full discussion of this reliance is included in Section 4.2 below under *Meteorological Forecasts.*

- Drought Indicators and Water Supply Condition

Drought is a recurrent feature of climate caused by reduced precipitation over an extended period of time resulting in a water shortage. In British Columbia, drought may be caused by combinations of insufficient winter snow accumulation, hot and dry weather or a lack of rainfall. Hydrological drought is associated with the effect of low precipitation on water levels in rivers, reservoirs, lakes and aquifers. Hydrological drought affects uses that depend on ground and surface water levels and stream flows.

While the Water Supply Outlook has been a part of the *Snow Bulletin* for many years, regular monitoring, analysis and reporting for drought has been conducted by the RFC only since the very dry summer of 2004. There has been an increasing emphasis placed on water supply and drought throughout the remainder of the last decade. Starting in 2005, this has resulted in a summer web-based "publication" generally called the *Streamflow and Water Supply Bulletin*. The word "*Drought*" is substituted for "*Water Supply*" in the Bulletin title when drought is part of the forecast.

The B.C. Government, in collaboration with Agriculture and Agri-Food Canada, has completed a *BC Drought Response Plan* (June 2010). This plan outlines the actions taken preceding, during and immediately following a drought to reduce its impacts. It includes communication steps required to ensure timely and appropriate action. The Plan uses a four level Drought Classification (Normal, Dry, Very Dry and Extreme) to explain the severity and appropriate level of response to drought conditions. The classification system is explained in Appendix 3.

The Drought Levels are a common language for describing forecasted or current conditions in a water basin or stream system. Early in the season (January to May) the levels will indicate the potential for drought conditions to occur in a given area. By late June, the likelihood and extent of drought can be fully assessed and Drought Levels will represent actual conditions and forecasts in a given area.

The Drought Levels set objectives and targets for appropriate response actions. Drought Response actions can range from effective and frequent communication, to voluntary conservation measures, mandatory restrictions and regulatory action. The Drought Levels are based on scientific indicators that assist in determining when to move from one drought level to another in a given area. Core indicators include snow levels, seasonal runoff for river basins, precipitation, and streamflow. This information can provide indications of the general conditions for a water basin.

The core indicators that are supplied to the Chair of the Interagency Working Group are:

- Basin Snow Indices;
- Seasonal Volume Runoff Forecasts;
- 30 Day Percent of Average Precipitation; and
- 7-Day Average Streamflow

These core indicators were chosen because data tends to be readily available, they are relatively easy to use and communicate, and the River Forecast Centre and other agencies have experience working with them. They can be used to speak consistently about water supply in particular watersheds while also allowing for meaningful comparisons across the province.

The RFC analyzes average streamflow data on a weekly basis. Results of this analysis may warrant escalating to a higher level of drought response more frequently than monthly.

***Recommendation 9*: Continue to publish the *Water Supply Bulletin* every year and the *Drought Forecast* in those years when this is important.**

- RFC Communications

There is a great public interest in flood events. As noted above, the RFC prepares flood advisories and drought information that is placed on the Ministry website and is sometimes released to the media, either directly or as a news release from the Minister's office depending on the urgency of getting the information out.

The RFC is seen as a highly credible source of information, free of political bias or filtering, and radio and television reporters often call looking for interviews and seeking local or even site-specific information about river levels and flows. Direct and frank discussions with the media are an excellent and low-cost way of reaching the public who may be affected by a flood, often faster and more effective than any bulletin or other attempt to notify people in a potentially affected area.

***Recommendation 10*: Ensure that the head of the river forecast centre and one or more forecasters receive media training and make sure that regular briefings of media are held during events. Also provide access for media to forecast spokespersons at regular intervals before and during an event.**

Throughout the snowmelt season, the RFC contributes to a web-based *Snow Bulletin* beginning in January and continuing until the snow has melted, with the last bulletin usually June 1 or in an unusual year, June 15. Once the snow has melted, usually starting in July, the RFC posts a *Streamflow and Water Supply Bulletin*. These bulletins are well respected and are used throughout the season by all clients groups.

4. Risk Evaluation

4.1 Risk Analysis

Living near rivers is inherently risky. We often speak about a 200-year event. This is the flood that would occur on average, once in every 200 year period or about 5 times in a thousand years. We give this a probability of one in 200 or one half of one percent probability of occurrence in any year(P=0.005). With sufficient investment in modeling, mapping and surveying, we can map the inundation area that shows the land that would be affected by a flood of this magnitude, which we call the 200-year floodplain. In areas where settlement and investment is large within the floodplain, society may choose to build dikes to provide some level of protection from floods up to this magnitude as has been done for parts of the Lower Mainland for example.

Classical risk analysis defines risk as the product of the probability of an event occurring multiplied by the consequence or the loss that the event would cause (R=PxC). This provides a quantitative risk number that is most useful for comparing alternatives. For the River Forecast Centre, there is no such simple approach to risk analysis. What is the value of a warning? How do you calculate the value of losses that did not occur because of a warning for a specific event? It is beyond the scope of this study to do case studies of past events to determine what flood mitigation actions were taken as a result of the RFC advice and to calculate the flood damages avoided as a result of these actions, although such studies might be instructive. For the purposes of this report, the author has looked at the concept of "adequate and timely" advice and sought to identify the sources of risk that would prevent advice from being adequate and timely as well as the trends and priority of these risks.

There are four sources of risk that might impair or prevent an appropriate and timely warning of an impending flood event. These are (1) data risk, (2) model risk, (3) technology risk, and (4) people risk. Each is dealt with below.

4.2 Data Risk

A forecast is the outcome of analysis of a large variety of data that is available in various forms, of differing accuracy and value, and comes at different times with differing "freshness" or currency. Key input data used by RFC staff for forecasting are:

- Meteorological forecasts.
- Snow survey data
- Hydrometric data
- Historical records.

Each is discussed below:

- ### Meteorological forecasts

The basic meteorological data for the operation of the RFC models are point (in time and space) values of precipitation and temperature, which are obtained from Environment Canada, BC Hydro and automated snow pillow sites. These data are supplemented with trends from observing recent changes in the data and forecasts of the near future meteorological data.

For fall flood forecasting, RFC staff depend on these meteorological forecasts from Environment Canada weather offices generally in the form of "heavy rainfall warnings". These are supplemented by data from snow pillow sites and other automated gauges operated by the Ministry of Transportation and the

Ministry of Forests. The heavy rainfall forecasts are themselves products of modeling, analysis and interpretation by meteorologists who are advising the media, the aviation industry and the public about the weather. There is a risk here because the RFC forecaster is then further interpreting the weather forecast in making a streamflow forecast. The RFC staff have access to Environment Canada meteorologists directly by telephone for discussions if necessary but the risk increases when making a forecast from a forecast.

In the 2005 Business Review, the following suggestion was made:

> *Consideration should be given to acquiring assistance from an experienced meteorologist during periods of flood watch to ensure weather data is being interpreted for local conditions on an hour-by-hour basis.*

This is still a valid suggestion for mitigating the forecasting-a-forecast risk. It has long been a desire of RFC management to put a meteorologist into the staffing of the RFC but there has never been sufficient funding for this purpose. Nevertheless, among the increased staff needs of the RFC is the need for a meteorologist to be integrated into forecast operations.

The RFC advises that in 2010, an alternative source of daily climate data for freshet modeling was implemented. Daily files from Canadian Meteorological Centre model output were received and incorporated into the WARNS runoff models (mainly for the Fraser River). This included forecasts for ASP climate stations, something formerly lacking in the old data source. Its usefulness is currently under review. Twice daily *Long Range Precipitation Reports*, which give quantitative forecasts of precipitation amounts for all of BC, have become available in the fall of 2010 and are now being used for fall flooding advisories.. There is a risk in using these data in that accessing meteorological data directly means it has not been reviewed by a seasoned meteorologist who could recognize if a data error has occurred. Such errors may not be picked up by the river forecasters. Another reason to have a meteorologist on the RFC staff.

***Recommendation 11*: Hire a qualified meteorologist into the RFC establishment to assist with interpreting weather data and forecasts from Environment Canada as well as incorporating raw weather data from the Canadian Meteorological Centre and other BC sources into RFC forecasts.**

During 2009 and 2010, there were additional coastal climate stations set up for the 2010 Olympics, and they were used by RFC staff for fall flood forecasting. However, these stations have now been decommissioned.

***Recommendation 12*: The use of the stations installed for the Olympic games should be reviewed for their value to augment the fall flood forecasts and perhaps a case could be made to re-commission one or more of them.**

- Snow survey data

Snow survey operations were described in the 2005 Business Review:

> *Snow Survey data used by the [RFC] is collected at a network of manual snow courses and at automated snow pillows. The manual snow survey is a network of 188 snow courses throughout BC where snow depth and water equivalency data are collected during the January 1 to June 15 period for use in flood risk and water supply analysis. Of the 188 snow courses, approximately 131 are managed by the provincial government and 57 by BC Hydro.*

Snow survey network analysis takes place on a ad hoc basis. Generally if there are impacts to a manual snow survey site (e.g. logging or fire impacts), its usefulness will be reviewed and it will be relocated, replaced or abandoned. Currently (2010) there are 177 manual snow courses being operated.

The 2005 Business Review reported there were 54 automated snow pillows. In 2009 the automated snow pillow network was reviewed and 7 stations were decommissioned (2 were giving poor quality data and 5 northern stations were removed due to the high cost of operation). Currently, 50 are in operation (30 operated by MOE, 17 by BC Hydro and 3 by Alcan).

The manual snow survey program is administered and implemented by regional water and flood safety staff.

The Snow Survey Program is an integral part of RFC operations. Both the manual and real-time automated snow and climate data collected are used for flood and water supply modeling and forecasting conducted by the RFC. The real-time climate data collected by the automated snow pillow program are used for fall and winter flood monitoring, and are key inputs for freshet modeling. The reliability of this real-time data would be more consistent if the RFC and Snow Survey Program were managed together. In addition, the larger staff would provide more flexibility and provide opportunities for cross-training and succession management.

***Recommendation 13*: Consider combining the River Forecast Centre and Snow Survey Program into one operational unit.**

- Hydrometric data

Environment Canada operates a network of hydrometric stations under the Canada-British Columbia Hydrometric Agreement. The hydrometric network mainly provides water level information. Stage-discharge curves exist for these sites and stream flow can be calculated from the recorded water level. In the 2005 Business Review, it was stated that there were 461 automated stations operating in BC of which 110 were considered important for flood warning purposes. Ninety-six of these stations provided real-time water level information for use in assessing river state and providing flood status reports.

Program funding comes from a variety of agencies, mainly BC Ministry of Environment, Environment Canada and BC Hydro. Funding uncertainty around the program had Environment Canada reluctant to fully commit to staff the program. This resulted in program capacity issues that affected flood operations as recently as the 2007 freshet.

The hydrometric network was last reviewed completely in 2000. In 2006 and 2007, funding was provided to expand the hydrometric network and a partial review was done before more stations were installed and existing stations were converted to provide real-time data. This funding was not sustained, however, and currently there are 455 stations operating of which 225 provide real-time data useful for flood forecasting (153 linked via satellite and 72 with telephone links). The network is less dense in the northeast of the Province and the increasing water use in the oil and gas sector has resulted in calls for more stations there. A complete network review is now underway and is scheduled for completion in early 2011.

During high flow events, stream gauging stations are often destroyed or damaged such that they no longer provide information. There is very little redundancy in the hydrometric system from a flood forecasting perspective.

Flood response in the fall floods and during the snowmelt runoff depend on the RFC forecasts which in turn rely on real-time water level data. Environment Canada has found it challenging to shift from being custodians of a historical streamflow record to being providers of real-time operational information. This implies having sufficient staffing to respond to data outages and having hardware and software to support the provision of real time data.

***Recommendation 14*: Continue the conversion of data capture to real-time to improve the timeliness of forecasting and assist with information for adaptive water management.**

- Historical records

Access to reliable historical data is important when forecasting. "How did the river behave the last time we saw a rainfall of this intensity in the basin?" is often the first question that comes to mind. There is a wealth of snow pack and stream flow data in paper files, on stand-alone RFC computers and in databases available through the RFC website. Regional staff have long asked for better access to this information. Even forecasters in the RFC say they spend too much time sifting through old information trying to find the piece they are looking for.

***Recommendation 15*: More effort needs to be made to organize, catalogue and store digitally the historical information in the RFC office.**

***Recommendation 16*: All new data, all historical data available digitally and all historical data that gets converted to digital format should be made available over the internet.**

4.3 Model Risk

The analysis of all this data is done through running a number of analytical models. Some models are watershed models that look at intensity, duration, location and areal extent of a storm and route the water, perhaps through a snowpack if any, overland to stream channels and then accumulate it to certain reference points on the river below. The output of the model is discharge at a point and perhaps water levels and velocities at that point. The WARNS Fraser River model is of this type.

Other models are regression models that look at snowpack or rainfall intensity and resultant peak flow events from a number of past flood or high-flow events over a range of rivers and watersheds. This provides a reference to conclude that a storm being forecast to have a certain intensity can be expected to produce flows similar to ones that have been recorded before with comparable storm intensities. This technique is often used to compare flows on an ungauged river with similar watershed characteristics (slope, aspect, elevation, forest cover, etc.) to a gauged basin for which there is information. The Volume Runoff Forecast system is a regression model.

Both types of models depend on accurate input data as discussed above, but also they must be calibrated correctly over a wide range of events and they must be maintained and recalibrated as changes occur in the watershed. In 2007, the Head of the RFC advised that the Fraser River model was "behaving strangely" and he suspected that he was beginning to see effects of the loss or forest cover from the pine beetle infestation on the river hydrology. Studies have been done on loss of the pine forests on forest hydrology but this new information has not been incorporated into the models.

A new updated model of the Fraser River could improve accuracy of the flow forecasts for the Fraser.

***Recommendation 17*: Replace the WARNS Fraser River Model with a more modern model that allows climate change to be better taken into account and which makes better use of the existing data.**

A more quantitative description of the forecast uncertainty is required. Information on the reliability of the forecast would help users better assess their situation and make appropriate decisions. An example of forecast uncertainty is the qualification often give in polls released to the public when statements are made such as "accurate within 3 percentage points 19 times out of 20". This means that the 95% confidence bands are plus or minus 3%.

***Recommendation 18*: Any new forecast model that is developed for the Fraser River (and others) should include quantitative estimates of forecast uncertainty.**

It can be expected that the models will become increasingly unreliable over time if effort is not routinely made to recalibrate them and update them with watershed changes. Staff are aware of this but do not have time with present staffing levels to recalibrate models. More discussion of this in the section on "People Risk" below.

4.4 Technology Risk

The River Forecast Centre relies heavily on computers and communications equipment. The RFC still uses the nearly outdated VAX, primarily for its role in managing the snow survey data used for forecasting, and production of the Snow Bulletin. Efforts to find a data system for not only snow data, but also climate and hydrologic data which can be integrated into models have not progressed. As a result, activities such as updating the Volume Runoff equations, 30-year normals, etc. have been delayed. Staff report that some data actually has to be reentered to move it from one computer system to another because of the inconsistent data formats and the difficulty in trying to transfer the data from one system to the other.

***Recommendation 19*: A systems analysis must be done for the RFC with a view to simplifying and modernizing the hardware and software that the RFC is using. This analysis needs to consider work flow and needs of the RFC, which may be unique to the needs of the rest of the Ministry in which they reside.**

The LRGS and "Station" data server located at the Emergency Management BC Vancouver Island office is now the primary data feed for real time automated snow pillow data. It also provides a backup source of satellite telemetry for Environment Canada hydrometric data. Development of a Postgres database on this server have been suggested. Lack of a database means much real time data is being lost .

***Recommendation 20*: As part of the systems analysis in the recommendation above, consider all the database needs of the RFC with a view to capturing all the data that can be used to enhance forecast capability.**

The RFC relies heavily on a myriad of Excel spreadsheets to process data for modeling, analysis, and presentation. This has long been recognized as lacking robustness, but has been the only alternative in the absence of a functioning database. These spreadsheets are generally one-offs, are not documented and in many cases reside on only one or two desktop computers.

***Recommendation 21*: Look at the use of Excel spreadsheets in the systems analysis recommended above to ensure that the needs for this type of software is part of the analysis.**

4.5 People Risk

In the end, it all comes down to the people that run the Centre. During an event, it is expected that there will be updates every few hours, and in a prolonged event, this goes on around the clock for days. Currently, there are two active forecasters in the RFC. They cannot be expected to run a 24 hour per day operation for any length of time. The former head of the forecast centre, who was the senior forecaster has recently resigned and there is no obvious successor. That position is currently under active recruitment with results unknown. The two existing forecasters are doing the best they can as the current fall flood season is underway.

It is instructive to see what other similar jurisdictions do for staffing their forecast centres. Alberta runs a River Forecast Centre in Edmonton from the Alberta Ministry of Environment. The combined states of Washington ,Oregon, Idaho and small portions of four other states are served by the United States Geological Survey from the Northwest River Forecast Centre in Portland. Comparative statistics for the jurisdictions are shown in the table below:

	British Columbia	**Alberta**	**USGS NW Region**
Land area (sq km)	944,735	661,848	740,182
Population (million)	4.5 (2010)	3.7 (2009)	11.5 (2006)
Hydrometric Stations	456	525	1079

Alberta has arguably simpler hydrology with about two-thirds the land area of British Columbia. The USGS Region is about three-quarters the size of British Columbia but has two and a half times as many people in the region. Nevertheless, the differences in the size of the area or population served cannot explain the differences in staffing noted below:

Type of Personnel	**British Columbia River Forecast Centre**	**Alberta Environment River Forecast Centre**	**USGS Northwest River Forecast Centre**
Manager or chief forecaster	1	2	1
River Forecaster / Senior Hydrologist	2	6	5
Hydrologist	0	0	3
Hydrologist Specialist	0	0	2
Hydrologist (intern)	0	0	1
Forecast Technologist	0	6	0
River Engineers	1	3	0
River technologists	0	2	0
Data Management / Systems Analyst	1.5	5	1
Senior Meteorologist	0	0	1
Meteorologist	0	0	2
Total	**5.5**	**24**	**16**

If BC had an equivalent number of forecasters per area served as Alberta, it would have 8 and one half forecasters. If an equivalent number per population served, there would be 7. The risk from using only 2 forecasters is extremely high. Illness, accident or just overwork and frustration could leave the Province without an ability to make any forecasts at all.

***Recommendation 22*: The number of working forecasters in the RFC needs to be increased from the current 2 to at least 6 and preferably more.**

The 5 forecasters in Portland are supported by 5 hydrologists; the 6 forecasters in Edmonton are supported by 6 forecast technologists and 5 river engineers and technologists. BC has 2 forecasters with a single river engineer. The forecasters need to be supported by an equivalent number of technologists, engineers and data or systems people to ensure that data is appropriately collected and managed, models are developed and calibrated and forecasts can be produced throughout a prolonged flood event. A staff of this size could, and should, include junior forecasters or trainees, which would allow for a succession plan to be developed for the Centre.

***Recommendation 23*: The forecasters need to be supported by at least 3 more staff with complementary skills in river forecast technology, meteorology, engineering and computer disciplines.**

The two recommendations above would require 7 more staff, bringing the total complement of staff in the River Forecast Centre in BC to at least 12, which is the bare minimum needed to meet the criteria of adequate and timely forecasts in a time of changing climate and rapid growth.

An observation made during this review is that there is a sense that the forecasters can only keep their heads down and make forecasts. Indeed they are very busy and that may account for the attitude. But there was also a feeling that perhaps they were not encouraged to improve the models. Certainly, they seemed reticent to put forward new ideas for improvement or even to challenge the assumptions in the models.

> "I can't think in government of a more important function than the River Forecast Centre nor can I think of any organization that gives greater value for the money."
>
> *Cam Filmer, Emergency Management BC*

***Recommendation 24*: Both the manager of the section that contains the RFC and the Head of the RFC should have the leadership skills to create an atmosphere of continuous improvement and to ensure that there is time and encouragement given for staff to challenge assumptions and seek to improve models.**

5. Looking to the Future

Two significant changes will be apparent in the coming decades that will affect the operations of the River Forecast Centre. The first is the changing demographics of British Columbia. The second is climate change. Each of this is discussed below.

5.1 Population Growth and Change

For their 2010 edition of *Population Projections for Canada*, Statistics Canada looked at a number of population growth trends for Canada into the future, projecting out as far as 2068. The population of the provinces is projected through a number of scenarios with different assumptions of fertility, mortality and immigration. The report concludes:

> *...according to the medium-growth scenario, the Canadian population should continue to grow in the next fifty years, at an average annual rate of 8.6 per thousand. While lower than the growth rate recorded during the period 1981 to 2009 (11.0 per thousand), this rate is higher than the rate projected by the medium-growth scenario of the preceeding edition (2.4 per thousand). Moreover, the Canadian population would not decrease in any of the projection scenarios, which is another difference from the preceeding edition.*
>
> *Nevertheless, these changes would not be large enough to alter some trends that began some time ago, such as the aging of the population, the unequal growth of the provinces and territories or the increasing importance of immigration in population growth. It seems likely that in the future, these trends will continue to pose some challenges for Canada.*

When looking at the population projections for British Columbia, Statistics Canada report Ontario and British Columbia would show an annual population growth higher than the national average in all scenarios. Therefore, their demographic share among the Canadian population would increase at least up to 2036.

Statistics Canada lists the population of British Columbia for April 1, 2010 as 4.510 million people. This is up 0.37% from January 1, 2010. It was the third consecutive quarter in which British Columbia led all provinces in population growth rate. Three-quarters of the increase was attributable to net international migration . The province also ranked first in net interprovincial migration for a third consecutive quarter. The various scenarios projected out 25 years to July 1, 2036 give population ranges for British Columbia from 5.748 million for the low scenario with the largest projection returning 7.004 million. What seems probable from reading the projections is that the BC population will exceed 6 million people in 2036. This means a population growth of 1.5 million people or 33% growth from the current 4.5 million to at least 6.0 million in 25 years.

Further, population aging in Canada would accelerate between 2010 and 2031, a period during which all baby boomers would reach age 65. Population aging would continue after 2031, but at a slower pace.

The BC Stats *Overview of the BC and Regional Population Projections* for August 2010, estimates that from 2009 to 2036, the BC population will increase by 36%. Further, BC Stats report that:

> *The overall retirement age (65+) population count and its share of total population will continue to increase significantly over the projection period (from 14.7 per cent in 2009 to 24.0 per cent in 2036). This will result in a significant increase in regionally focused demand for community services for this age group.*
> *The very senior (80+) population will also increase significantly, growing from 4.1 per cent of the population in 2009 to 7.4 per cent in 2036.*

BC Stats reported in 2009 that the population of the Greater Vancouver Regional District (now Metro Vancouver) was 2.319 million people or over half the current BC population.

There are substantial disparities with respect to projected growth among the 29 British Columbia Regional Districts. The areas projected to grow faster than the projected provincial average are:

- Squamish-Lillooet
- Fraser Valley
- Central Okanagan
- Greater Vancouver
- Comox Valley
- Nanaimo

There are regional differences with respect to age as well. Currently, the population 65 and over (as a percent of total population) is much smaller in most of the remote areas, and greater in the more populous, southern regions of the province. areas with the greatest percentage of population in the age group 65+ are the Kootenays, Vancouver Island/Coast and Thompson Okanagan.

The significance for this study of the above pattern of population change is twofold, Firstly, to look at the population growth. The fastest growing areas all contain significant areas exposed to flooding. With the expected increases in population listed above, we will see an increase in densification of existing settlements in floodplain areas. This means the population at risk will increase and the value of infrastructure at risk will go up. Secondly, we will see development in new areas that are not currently developed. There will be pressure to place some of this development in areas that are within the floodplain, increasing the risk. Even if these floodplain areas are protected by dikes, they are still in floodplains and depend on the design, construction and maintenance of the dikes, which only protect up to a flood of the design magnitude if they do not fail. Further construction of dikes to protect additional areas, necessarily narrows the floodplain, thus restricting the area available for flood flows, potentially raising the flood levels and the risk for people living in existing developed areas in the floodplain.

It is inevitable given the projections for population growth, that the numbers of people at risk from flooding and the value of infrastructure at risk will grow and the magnitude of that risk will significantly increase over the next 25 years.

***Recommendation 25*: In-depth studies of demographics within a watershed or floodplain should be done to determine where risk is increasing and the ability to forecast flooding in these areas should be assessed.**

***Recommendation 26*: Assess models for forecasting floods and droughts in the higher growth areas and higher risk areas to prioritize work on building new or improve existing models.**

Secondly, to deal with the aging population. Older people are less mobile; they cannot respond as quickly to an evacuation alert and they may not even be able to evacuate themselves. Again, the population projections show that more of the older people are settling in the areas that have the greatest percentage of the population within areas at risk of flooding.

This underlines the importance of the need for accurate and timely warnings to evacuate people only if necessary and to have adequate time to carry out that evacuation.

***Recommendation 27*: Conduct research in-house or contract research to make models more responsive and more accurate. Involve the forecasters in this work to ensure they always understand the assumptions and limitations in their tools.**

5.2 Climate Change

First, this section begins with a discussion of the global picture of climate change and the driving forces. Then we turn to the British Columbia situation as well as it can be seen at this time. Based on this some conclusions can be drawn about the need for and the value of forecasts.

- ### The Global Picture

In 2007, This Intergovernmental Panel on Climate Change (called the IPCC) released their Fourth Assessment Report. In it they stated:

> *Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level.*
>
> *At continental, regional and ocean basin scales, numerous long-term changes in climate have been observed. These include changes in arctic temperatures and ice, widespread changes in precipitation amounts, ocean salinity, wind patterns and aspects of extreme weather including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones.*

The IPPC states plainly:

> *Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations.*

The 2007 IPCC report was based on data up to 2006. This report was updated in a document called the *Copenhagen Diagnosis,* which was released on November 24, 2009. The *Copenhagen Diagnosis* is not an official IPCC report but it was compiled by 26 climatologists, 14 of whom were IPCC members. It is a summary of the hundreds of scientific papers published since the 2007 IPCC Fourth Assessment Report.

The *Diagnosis* states that global warming continues to track early IPCC projections based on greenhouse gas increases. But the report says that without significant mitigation, the global mean warming could reach as high as 7° Celsius by 2100. An illustration of the scale of such an increase is that we are now only around 5° C warmer than during the last ice age.

The general consensus is that with warming, there is more energy in the global atmospheric system that determines the weather. This means that we can expect both the intensity and the frequency of floods and drought to increase as the globe continues to warm.

- The BC Context

Work continues at many research centres around the globe to bring the global climate models down to sub-continental and even regional scale. In addition, research is being done by taking local observations and documenting observable trends. Both of these give us some idea of what to expect in BC.

Dr. Stuart Cohen, a senior researcher with Adaptation and Impacts Research Division of Environment Canada, and an Adjunct Professor with the Department of Forest Resources Management of the University of British Columbia, published in 2004 a study on runoff in the Okanagan. He shows how the hydrograph shape is changing in that the peak is occurring sooner and will be lower due to reduced snowpack and there will be a longer period of low flow in summer.

This can also be seen in data from the River Forecast Centre graphs of April 1 snow water equivalent. These graphs of long-term stations show the trend over several decades of the spring snow levels declining as shown in these examples:

- 73% reduction since 1957 at the Nazko station (Upper Fraser)

- 53% reduction since 1951 at the Canoe River station (Upper Fraser)
- 44% reduction since 1945 at the Brookmere station (Nicola)
- 19% reduction since 1968 at the Stave Lake station (Lower Fraser)

While this might indicate a reduced snow melt flood risk in the interior and northern basins, it brings with it an increased summer drought risk.

Climate change will produce both warmer and wetter winters or warmer and drier winters depending on the En Nino Southern Oscillation. The warm/dry winters will result in a generally smaller snowpack and thus lower summer flow. The warm/wet winters will bring more fall precipitation right through December. This will fall as rain in the valley bottoms and may be snow or rain in the mountains. The risk of rain-on-snow flooding will be increased. Water managers need to plan for both of these cycles and we could get years of each scenario.

We will see more extreme events: more storms leading to flooding and more droughts. These floods and droughts will happen more often and they will be more severe. The Canadian climate model projects that the size of extreme precipitation events may increase by an average 10 mm or so across Canada. This can cut in half the average time lapse between events of a specific size. For example, an 80 mm rainfall event, which now occurs about once every 80 years in the dry interior, may occur once every 50 years by 2050 and every 25 years by 2090 (Source: Climate Research Branch, Meteorological Survey of Canada).

We have some observed data that shows we are already experiencing a storm rainfall frequency increase. The number of days where the daily precipitation exceeded 80mm at the Cowichan Lake Forestry station showed an increase from just over 4 days (in a 5-year period) in 1955 to over 7 days by 2000. Similarly Estevan Point shows an increase from 10 days in 1955 to about 15 days in 2000.

What does all this mean on the ground? The following paragraphs examine impacts on some areas.

First, in communities, the good news is cost savings for heating of municipal infrastructure and cost savings for snow removal. However, there will be an increased and prolonged summer water demand with a concomitant need for a strong and effective water conservation program. Communities will also be looking for additional water sources and larger storage.

The existing storm water drainage systems will be insufficient. Rain intensities will be higher and durations will be longer than most storm drains have been designed for resulting in more events where there is water running down the roadway. We already see communities requiring new development to reduce impervious areas and keeping storm water on the land longer through retention areas. Some communities even require no increase in runoff from developed areas over the undeveloped state.

Community flood Protection will require serious review with more floodplain planning, better flood protection works and flood proofing requirements behind dikes. Most importantly, there will be more emergency response planning and greater call for earlier and more accurate warnings of flood events.

For the transportation sector, snow removal costs should go down although avalanche risk will increase in some years. Icing problems on the roads may increase with more areas around 0°C, above zero in the day, below in the night. Highway drainage will be an issue – from the road surface and in road side ditches and there will be a need to check capacity and design parameters of culverts and waterway openings for bridges. Some transportation routes may ultimately be changed due to flooding, avalanches or the high cost of maintenance.

There are some significant benefits to agriculture. The longer frost-free season will have increased growing degree days. There will also be an increased demand for locally-grown produce due to rising transportation costs and carbon constraints. Fortunately, we should experience increased crop productivity in mid to high latitudes

However, there will be summer water shortages and increasing conflict between agricultural water users and other users and instream flow needs. There is also an increased potential for pests and diseases along with more likelihood of heat stress on livestock

Storm runoff will cause erosion, may deposit gravels and debris on low farmland and may flood these lands. Marine shoreline lands or islands or delta lands may become unsuitable for agriculture as sea level rise and salt water intrudes.

Impacts on aquatic ecosystems have not been comprehensively evaluated. Both floods and drought will affect riparian vegetation and instream habitat such as spawning areas. Climate change may already be affecting migration patterns of salmon and other cold water fish. Increasing temperature will certainly affect cold water fish species. In 2004 and 2005 the temperature of the Fraser River at Hope exceeded 20°C on several occasions. This is the temperature where risk to salmon becomes serious. They cannot migrate upstream hundreds of miles against temperatures of 20°C or more.

One thing is clear there will be increasing competition between fish and agriculture, not just for water but for sufficient flow volumes to keep the streams cool.

There are several steps that most climate change scientists agree upon:

- We all need to accept the changes that are coming and anticipate them.
- We need to start planning scenarios to figure out approaches for different climate impacts.
- We should expect surprises. Flexibility will be critical to respond to the unexpected.
- We must plan for the long term. Adaptive responses will need to keep changing during this time.

As climate change impacts become more apparent and start to affect the lives of citizens every day, there will an increasing demand for more information. Improved forecasting will be critical, as will real-time data to allow for adaptive management of resources during climate extremes.

***Recommendation 28*: Review existing hydrometric and snow data bases and examine available meteorological forecasts with a view to increasing data availability for protection of higher growth areas.**

***Recommendation 29*: More in-depth studies of the demographic trends for British Columbia should be used to prioritize the development and extension of FRC forecasts for areas that are expected to have the growing populations, especially if that population will have a greater proportion of vulnerable people.**

6. Program Delivery Options

As this report was being written, organizational changes were happening first in the Ministry of Environment and then, on October 25, 2010, throughout the natural resource sector of government. When releasing Order In Council 652 that created a new Ministry of Natural Resource Operations, Premier Campbell said that "*this new structure would streamline government processes for critical natural resource industries to ensure we can better attract global investment and turn proposed projects and investments into actual worksites and jobs*". The stated intention was that ministries such as the Ministry of Environment would continue to make the policy and set the standards but the new Ministry of Natural Resource Operations would deliver the ministry's programs in a more streamlined and integrated way.

The new structure was being rolled out as this report was being finalized in November. At this time, questions were raised about the best fit for the River Forecast Centre in the new structure of government. This section examines some options at a very high level. Although every attempt was made to keep this discussion factual, some speculation was unavoidable.

6.1 Move the RFC out of the provincial government

It might be possible to relocate the RFC outside of the provincial government, either completely in the private sector or as a independent Crown agency. It would be worth exploring the market to see if there are cost recovery possibilities for some of the RFC products but it is not expected that the revenue would be sufficient to support the full range of public need for the service. Protection of the public is seen as one of the basic roles of government and any move to privatize river forecasting would not likely receive any public support without a very strong rationale.

Some aspects of the program could perhaps be done under contract but it is difficult to see much cost saving. A private operator would either want to be indemnified from liability for losses if the forecast failed to provide adequate warning or the company would have to charge a very large fee to obtain sufficient insurance to protect it from such a possibility. The government had to provide such an indemnity for the private companies that helped the supervision of the urgent repairs to the dikes in 2007 as the companies threatened to pull their staff away if they would be expected to bear the risk of dike failure. No obvious business case for privatization can be easily seen.

There is no strong argument that can be made that public safety will be improved by moving the RFC operations into the private sector.

6.2 Transfer the RFC to another order of government

The federal government is already in the weather forecasting business, perhaps they could do flood forecasting as well. The Meteorological Service of Canada (MSC), part of Environment Canada, has been providing weather forecasts across Canada since 1871. Weather systems are large and major weather events can affect large parts of the North American continent, certainly well beyond provincial borders. Data for weather forecasting comes from satellites, from offshore data collection platforms and from weather stations across Canada. The transboundary nature of weather has been the rationale for the federal government being in the weather forecasting business almost since confederation.

Floods and droughts are more of a local phenomenon. Even a major, widespread event will rarely cross a provincial border. Response to these events begins at the local level and, if the event grows, expands to a regional and even provincial level. If the federal government participates, they do so by helping pay some of the recovery costs under federal-provincial disaster mitigation agreements.

Canadian's fascination with the weather and the fact that weather can affect our lives on a daily basis has meant that weather forecasting is big business. The MSC makes a significant return to its budget from charging the television stations and other media for weather forecasting services . The MSC also has a contract with Nav Canada, the country's civil air navigation service provider. Weather products and professional weather services bring in nearly $50 million of the total approximately $80 million in annual revenue that comes into Environment Canada. It unlikely that a business case could be made for RFC products and services that would make it an attractive business proposition for Environment Canada.

Because of the strong ties to response to flood and drought events and the local and regional nature of that response, the provincial government is seen to be the more rational place for the RFC. In addition, the lack of a strong financial business case for such a transfer would hamper any attempt to make such a transfer. Nevertheless, the strong links between weather forecasting and flood forecasting are recognized.

River forecast functions seem to fit better inside the provincial government context.

6.3 Move the RFC to Emergency Management BC

Because of the strong links of the RFC to emergency response efforts, the suggestion has been made to move the RFC to Emergency Management BC (EMBC). Certainly this would strengthen the link with EMBC and put the RFC very close to the centre of emergency management. EMBC is an action-oriented organization that stresses readiness to respond to emergencies. It excels at preparation, practice and swift response. The RFC is more science-based and it must give accurate, timely and measured responses. Not every RFC advisory is a precursor to an emergency.

Both drought and water supply forecasts are not emergency functions (at least not initially). Drought is a pervasive hazard that builds gradually. The input from the river forecast centre is used to adjust the drought management responses as conditions become drier. Similarly the water supply forecasts are used by communities and irrigation districts and others to manage their reservoirs and to advise their water users about the supply. This essential work might not be given the same priority in an organization devoted to emergency response. Nevertheless, a close working relationship between EMBC staff and the RFC is important.

This concept was explored with a senior member of EMBC and he said he did not support moving the RFC to EMBC. He reiterated the importance of the RFC to emergency management and he also expressed concern about the lack of resources available to the RFC currently. He also said that a good working relationship between the RFC and EMBC was essential.

The RFC is seen as a better fit within a line ministry, not in EMBC.

6.4 Keep the RFC in the Ministry of Environment

The status quo is always an option. It is easier and often better to leave people alone and let them focus on the important job they have to do rather than disrupt them with reorganization and perhaps a physical move; especially now (November) when the winter rains have already resulted in flood warnings and flooding.

According to Backgrounder 3 of the Press release accompanying OIC 652, "water and air monitoring and reporting" will remain in the Ministry of Environment. It is assumed that this includes the management of the hydrometric network and snow surveys. These monitoring data are, with the meteorological forecasts, the essential inputs to all of the work of the RFC. It is vitally important that a close working relationship is maintained between those who use the data (the RFC staff) and those who manage the collection of it. This separation has widened in recent years with one of the key hydrometric positions being located in Vancouver at the University of BC, even though still in the same ministry.

The Ministry of Environment still maintains a strong science focus and monitoring data collection and analysis are done throughout the Ministry. The necessary development of hydrologic models and their calibration in the RFC can be done in an atmosphere of support for data management and modeling that may not be available in an operations organization.

However, with RFC staff in the Ministry of Environment and operations staff and water management staff in the Ministry of Natural Resource Operations, the vital RFC link with operations becomes more tenuous when it must bridge the gap between ministries. Regional operations are seen as the primary internal client and the first priority of the RFC staff. Keeping the RFC in the Ministry of Environment would signal that the organizational relationship between the RFC staff and the input data management staff is more important than the link between the RFC staff and the operations staff that use the forecasts.

6.5 Move the RFC to the Ministry of Natural Resource Operations

Perhaps the strongest organizational link is between RFC staff and operational staff and thus moving the RFC to the new Ministry of Natural Resource Operations (MNRO) must be examined. Following on the discussion in Section 6.4 above, it follows that moving the RFC staff into the MNRO signals that the link with operations is more important than the link with the data. In fact, both relationships must be maintained for the RFC staff to do their jobs successfully.

The downside to moving the RFC to the MNRO is that MNRO is intended to be an action-oriented organization that may not have much time or resources for the science that is needed to keep the RFC current with the rapid changes that are happening both in the technology and in the climate itself. The Ministry of Environment may be more supportive of reviewing current literature and studying emerging research that is necessary to keep the forecast models current.

If the RFC is to be moved into MNRO, it strengthens Recommendation13 regarding integrating the RFC and the Snow Survey Program.

6.6 Program Delivery Summary

In times of reorganization hard choices have to be taken. This is one of those times. It is an axiom that it is not the organizational model that decides success or failure, it is the relationships among the people. However, it is also recognized that the organizational model can help to build or support those relationships. Normally, it is the intent of any reorganization to provide for the development of those relationships that are essential to achieving the desired business results. The following recommendations are given with relationship building in mind:

***Recommendation 30*: Seriously consider the benefits of moving the River Forecast Centre into the Ministry of Natural Resource Operations.**

***Recommendation 31*: If the RFC is to be moved into the Ministry of Natural Resource Operations, look at the integrating or co-locating it with the Flood Safety Section of the Water Management Branch where there is also some modeling expertise.**

***Recommendation 32*: If the RFC is to be moved into the Ministry of Natural Resource Operations, the rationale for moving the Snow Survey Program as well is strengthened because the manual snow surveys are carried out by MNRO staff.**

***Recommendation 33*: If the RFC is to be moved into the Ministry of Natural Resource Operations, ensure that there are institutional arrangements that provide the RFC staff with meaningful input into network design, station choices, operation schedules, etc. Examples of such arrangements include regularly scheduled meetings and a formal role on a network management steering committee.**

7. Summary of Recommendations

The River Forecast Centre must always be changing and evolving to successfully fulfill its mandate. With climate change, the hydrology that we have come to understand is also changing. The watersheds themselves are changing from development (roads, stream channelization, pavement and other impervious areas), and from loss of trees that shade the snowpack and slow the melt, from logging and from the pine beetle infestation. The risks are changing with more people in the Province, living and building in floodplains and depending on surface water for a reliable water and power supply. In addition, the technology is changing, which creates new opportunities at the same time as it causes problems with outdated and eventually unsupported and unusable equipment and data that cannot be accessed. These changes demand that the data available, the models, the technology and the skills of the people in the RFC also change to keep up.

***Recommendation 1*: Staffing in the River Forecast Centre must be adequate to provide for briefings and selected one-on-one conversations with field staff who respond to the emergency events. Participation by RFC forecasters in briefings should be encouraged.**

***Recommendation 2*: The Head of the River Forecast Centre should work with EMBC to gain a better understanding of the needs of this wider client base with a view to improving the content and value of the forecasts for local government and other first responders.**

***Recommendation 3*: At a minimum, the VRF for the current 7 rivers should be continued.**

***Recommendation 4*: Regional managers should be polled to see what additional forecasts are necessary for improved operations.**

***Recommendation 5*: VRF for at least the 7 current rivers should be made available to the public in the web-based Snow Bulletin.**

***Recommendation 6*: Update the current Fraser River Model (the WARNS model) and recalibrate with new data.**

***Recommendation 7*: The gauge on the Fraser River at Mission must have a cross-section profile that is regularly updated and a stage-discharge relationship that is kept current.**

***Recommendation 8*: Cross training of staff and a succession plan for the forecasters is essential to provide for business continuity of RFC functions.**

***Recommendation 9*: Continue to publish the *Water Supply Bulletin* every year and the *Drought Forecast* in those years when this is important.**

***Recommendation 10*: Ensure that the head of the river forecast centre and one or more forecasters receive media training and make sure that regular briefings of media are held during events. Also provide access for media to forecast spokespersons at regular intervals before and during an event.**

***Recommendation 11*: Hire a qualified meteorologist into the RFC establishment to assist with interpreting weather data and forecasts from Environment Canada as well as incorporating raw weather data from the Canadian Meteorological Centre and other BC sources into RFC forecasts.**

***Recommendation 12*: The use of the stations installed for the Olympic games should be reviewed for their value to augment the fall flood forecasts and perhaps a case could be made to re-commission one or more of them.**

***Recommendation 13*: Consider combining the River Forecast Centre and Snow Survey Program into one operational unit.**

***Recommendation 14*: Continue the conversion of data capture to real-time to improve the timeliness of forecasting and assist with information for adaptive water management.**

***Recommendation 15*: More effort needs to be made to organize, catalogue and store digitally the historical information in the RFC office.**

***Recommendation 16*: All new data, all historical data available digitally and all historical data that gets converted to digital format should be made available over the internet.**

***Recommendation 17*: Replace the WARNS Fraser River Model with a more modern model that allows climate change to be better taken into account and which makes better use of the existing data.**

***Recommendation 18*: Any new forecast model that is developed for the Fraser River (and others) should include quantitative estimates of forecast uncertainty.**

***Recommendation 19*: A systems analysis must be done for the RFC with a view to simplifying and modernizing the hardware and software that the RFC is using. This analysis needs to consider work flow and needs of the RFC, which may be unique to the needs of the rest of the Ministry in which they reside.**

***Recommendation 20*: As part of the systems analysis in the recommendation above, consider all the database needs of the RFC with a view to capturing all the data that can be used to enhance forecast capability.**

***Recommendation 21*: Look at the use of Excel spreadsheets in the systems analysis recommended above to ensure that the needs for this type of software is part of the analysis.**

***Recommendation 22*: The number of working forecasters in the RFC needs to be increased from the current 2 to at least 6 and preferably more.**

***Recommendation 23*: The forecasters need to be supported by at least 3 more staff with complementary skills in river forecast technology, meteorology, engineering and computer disciplines.**

***Recommendation 24*: Both the manager of the section that contains the RFC and the Head of the RFC should have the leadership skills to create an atmosphere of continuous improvement and to ensure that there is time and encouragement given for staff to challenge assumptions and seek to improve models.**

***Recommendation 25*: In-depth studies of demographics within a watershed or floodplain should be done to determine where risk is increasing and the ability to forecast flooding in these areas should be assessed.**

***Recommendation 26*: Assess models for forecasting floods and droughts in the higher growth areas and higher risk areas to prioritize work on building new or improve existing models.**

***Recommendation 27*: Conduct research in-house or contract research to make models more responsive and more accurate. Involve the forecasters in this work to ensure they always understand the assumptions and limitations in their tools.**

***Recommendation 28*: Review existing hydrometric and snow data bases and examine available meteorological forecasts with a view to increasing data availability for protection of higher growth areas.**

***Recommendation 29*: More in-depth studies of the demographic trends for British Columbia should be used to prioritize the development and extension of FRC forecasts for areas that are expected to have the growing populations, especially if that population will have a greater proportion of vulnerable people.**

***Recommendation 30*: Seriously consider the benefits of moving the River Forecast Centre into the Ministry of Natural Resource Operations.**

***Recommendation 31*: If the RFC is to be moved into the Ministry of Natural Resource Operations, look at the integrating or co-locating it with the Flood Safety Section of the Water Management Branch where there is also some modeling expertise.**

***Recommendation 32*: If the RFC is to be moved into the Ministry of Natural Resource Operations, the rationale for moving the Snow Survey Program as well is strengthened because the manual snow surveys are carried out by MNRO staff.**

***Recommendation 33*: If the RFC is to be moved into the Ministry of Natural Resource Operations, ensure that there are institutional arrangements that provide the RFC staff with meaningful input into network design, station choices, operation schedules, etc. Examples of such arrangements include regularly scheduled meetings and a formal role on a network management steering committee.**

8. Appendices

Appendix 1: Contract Schedule A

From Schedule A of the contract for this report.

PART 2. SERVICES:

1. The Contractor must conduct a water supply and river forecast function business review and provide a risk assessment of the water supply and river forecast function of the Science and Information Branch, Water Stewardship Division. The review must include consideration of the following:
    a. **Current Status Assessment**
        i. Mandate
        ii. Clients
        iii. Components
            1. Inputs
            2. Processes
            3. Outputs
        iv. Confirm change since 2005 review
    b. **Future Casting & Gap Analysis - ~2 & 5 years out**
        i. What questions should we be positioning ourselves to answer? What should we consider, e.g.:
            1. What level of river forecasting is appropriate?
            2. What options might exist to do the work we do now more efficiently?
            3. What else should be considered? (e.g. needs in response to climate change adaptation)
            4. How do other jurisdictions approach this function?
        ii. What additional needs might our clients have?
2. The contractor must complete a report of its findings and recommendations, including:
    a. An overview of the current water supply and river forecast functions management, organization structure and resources
    b. An overview of the River Forecasting System
    c. Client needs and a risk assessment of results if those client needs are not met
    d. Options for the water supply and river forecast functions and a risk assessment of the options

Appendix 2: Persons Interviewed

Persons interviewed for this study (listed in the order they were contacted)

Name	Organization
Fern Schultz	Ministry of Environment
Bill Kuhnke	Ministry of Environment
Luanne Chew	Ministry of Environment
Scott Jackson	Ministry of Environment
Allan Chapman	Oil and Gas Commission
Normand Bilodeau	Ministry of Environment (at time of interview)
Valerie Cameron	Ministry of Environment (at time of interview)
Brian Symonds	Ministry of Environment (at time of interview)
Glen Davidson	Ministry of Environment (at time of interview)
Larry Barr	Ministry of Environment (at time of interview)
Cam Filmer	Emergency Management BC
Chris Duffy	Emergency Management BC
Dwayne Meredith	Emergency Management BC
Neil Peters	Ministry of Natural Resource Operations
Jeff Rowland	City of Prince George
C. David Sellars	Water Management Consultants (now retired)
Steven Waugh	Central Coast Regional District
Dan Hogan	Ministry of Environment

Appendix 3: Drought Level Classification

In BC a four level Drought Classification is used to explain the severity and appropriate level of response to drought conditions.

Drought Level Classification:

Level	Conditions	Significance	Objective	Target
1 (Green)	Normal Conditions	There is sufficient water to meet human and ecosystem needs	Preparedness	Ongoing reductions in community water use
2 (Yellow)	Dry Conditions	First indications of a potential water supply problem	Voluntary conservation	Minimum 10% reduction
3 (Orange)	Very Dry Conditions	Potentially serious ecosystem or socioeconomic impacts are possible	Voluntary conservation and restrictions	Minimum additional 20% reduction
4 (Red)	Extremely Dry Conditions	Water supply insufficient to meet socio-economic and ecosystem needs	Voluntary [illegible] restrictions and [illegible] response	Maximum reduction
Loss of Supply		Potential loss of a community's potable or fire fighting supply	Emergency response	Ensure health and safety