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AN INDEPENDENT REVIEW OF THE 1997 RED RIVER FLOOD

Flood Forecasting

The Manitoba Water Commission
March 31, 1998

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TABLE OF CONTENTS

FLOOD FORECASTING

Introduction

Flooding in the Red River Valley typically occurs during the spring as a direct consequence of the melting of the winter snowpack. The main factors which contribute to potentially severe flooding conditions are: i) high water content in the soil at the time of the freeze up in the fall; ii) heavy snowpack accumulation during the winter; iii) rapid melting or a south to north migration of snowmelt; and iv) heavy spring rainfall.

The large size of the Red River basin can lead to contrasting runoff patterns within the various portions of the basin due to spatial variations in meteorological conditions. Substantial contributions to major flood flows usually occur from the U.S. portion of the basin. The Manitoba tributaries, including the Assiniboine River, also contribute substantially to the flow in the Red River from Emerson through the City of Winnipeg and on to Selkirk. The complexity of this river system requires a forecasting approach that recognizes the potential diversity in runoff contributions from the various portions of the catchment area.

Water Resources Branch Forecasting Procedures

The Branch's Hydrologic Forecast Centre (HFC) produces two flood estimation products. The first of these products is a flood outlook, which is initially released in February and is updated in March and April, depending on weather conditions. The flood outlooks provide an early indication of the potential for spring flooding. Flood outlooks are determined based mainly on existing soil moisture and snow cover information and different scenarios for future weather conditions. Because future weather is uncertain, three scenarios are produced comprising a median outlook based on average future weather, a lower decile based on favourable weather conditions and an upper decile based on unfavourable (severe) future weather conditions. In theory, the actual water level should fall between the predicted upper and lower decile levels 80 percent of the time, on average.

The second flood estimation product is an operational forecast. Operational flood forecasts are produced and released on a daily basis during the spring runoff period and are based on observed and predicted runoff and streamflow. A forecast range is used to express uncertainties due to unknowns. These forecasts are based on favourable future weather conditions unless otherwise noted.

The forecasting procedures used by the HFC involve an index approach to estimating spring runoff. Streamflows and the resulting water levels are estimated using methodologies such as unit hydrograph analysis, streamflow routing, and stage-discharge relationships. There are three basic steps required to determine the water level at various locations within the basin. The three steps involve the estimation of: i) the runoff depth; ii) the peak rate of streamflow at a given point in the river; and iii) the peak water level that results from the peak streamflow rate.

Runoff Depth

Runoff depth is defined as the amount of water, expressed as a depth, that will leave the basin as a result of snowmelt and/or spring rainfall. The product of the runoff depth and the basin drainage area will give the total volume of water comprising the runoff event. The runoff depth is estimated based on: i) the water content of the snowcover plus the effective spring rain; ii) the soil moisture, which is calculated through an Antecedent Precipitation Index (API) and which affects the division of the precipitation and snowmelt between infiltration and runoff; and iii) the rate of snowmelt defined as a melt index. The three contributing factors noted above are used to calculate the runoff depth. This is done either based on a statistical approach, in which an empirical, nonlinear regression approach is used, or through a graphical technique. In the graphical technique, relationships that have been developed from past flood events are used to relate the three contributing factors to the runoff depth. Additional relationships have been developed for predicting the peak streamflow rate and the peak water level at Emerson, the most upstream point in the Canadian portion of the Red River Valley. These relationships additionally use the runoff in the previous spring and a winter temperature index for predicting the streamflow and water level. The latter factor is used as a measure of the losses from the snowpack due to sublimation and may be an indicator of ground frost conditions that also affect runoff. The estimation of the runoff depth through the procedures noted above relies heavily on experience derived from past flood events.

Peak Streamflow Rate

The rate of streamflow in a river is defined as the number of volume units of water that are passing a given point each second. The streamflow rate (or simply the streamflow) is typically expressed in cubic meters per second (cms) or cubic feet per second (cfs). The runoff depth that is estimated for the catchment is used as input to a unit hydrograph approach to determine the streamflow hydrographs for key points within the catchment area. A hydrograph is a time history of the streamflow rate at a given location from which the peak streamflow rate can be determined. Two factors are important in determining the shape of the hydrograph that results from the runoff of the melting snowpack. One factor is the amount and timing of precipitation that occurs during the melt event and the other is the rate at which melting occurs. Both factors affect the amount and the timing of the runoff. Since both the amount of precipitation and the melt rate are affected by unknown weather conditions, the forecasting procedures provide a range of outcomes for different future weather conditions. For this purpose, Manitoba Water Resources has unit hydrographs for slow, moderate, and fast melt rates.

Within the mainstem of the Red River, streamflow rates at downstream locations are determined by "routing" hydrographs calculated for upstream locations through a segment of the river channel. The Water Resources Branch accomplishes this using the Muskingum flood routing technique. The Muskingum technique is a hydrologic routing method that is based on mass conservation and an implicit storage-discharge relationship for the channel segment. Using the routing technique, hydrographs at various points along the mainstem of the Red River can be calculated based on the inflow hydrograph at Emerson and contributions from tributaries that add to the streamflow between Emerson and the downstream point(s) of interest. This is a very important part of the forecasting process considering that a large portion of the total streamflow in the Red River can come from the U.S. portion of the basin and hence passes through Emerson. For example, in the 1997 Flood of the Century, it is estimated that greater than 80% of the total flow originated from the U.S.

When calculating flood outlooks, the streamflow forecast for Emerson is obtained from forecasting procedures derived by Manitoba's HFC for the U.S. portion of the watershed. During the period for which operational forecasts are calculated, streamflow forecasts at Emerson are obtained from a combination of forecasted and measured streamflow for the U.S. portion of the basin. This information is obtained primarily from the U.S. National Weather Service and the U.S. Geological Survey. Manitoba's HFC assesses the information from the U.S. agencies and develops a streamflow hydrograph for Emerson that is then used for flood routing in the Manitoba portion of the watershed.

Peak Water Level

The water level in the river is undoubtedly the variable of greatest interest to those individuals potentially affected by a flood event. The expected water level at any point within the forecast region is estimated based on the streamflow rates expected in the river. Estimates are obtained using a "rating curve" that relates the water level at a given location to the streamflow rate. When the streamflow is contained within the channel cross-section, the requisite rating curves are generally sufficiently well defined to facilitate an accurate estimate of the expected water level. However, when streamflow occurs out of the main channel, defining the relationship between the streamflow rate and the corresponding water level becomes much more difficult. This is especially true when flow magnitudes exceed those that have been recorded at the location in the past. In situations such as this, accurate estimates of the water level for a given streamflow rate require the adoption of more complicated modelling procedures. Such approaches are not, at present, a part of the Water Resources Branch forecasting approach.

Data Requirements

All flood forecasting methods rely on the availability of representative hydrologic and meteorological data. In many respects, the quality of forecasting results can only be as good as the data that are used as inputs to the methodology. It is thus important that the design and implementation of a forecasting approach consider the data that are available and any limitations imposed by the available data network. Data that are required for flood forecasting in the Red River Valley include: i) soil moisture data to define the degree of saturation of the catchment at the time of freeze up and during the winter and spring periods; ii) snow data at various locations to define the extent and water content of the winter snowpack that is available to generate runoff; iii) meteorological data in the form of spring precipitation and temperature data to define the total basin moisture inputs and to characterize the rate of melting of the snowpack; and iv) streamflow data for use in the preparation of the operational forecasts.

In recent years, airborne gamma snow surveys have been used to help define the water content (soil moisture and snowpack) of the catchment at the onset of the spring snowmelt. This information is obtained through aerial surveys and thus the data gathered in this manner provide a good spatial characterization of the water content of the catchment. A good spatial representation of the water content is difficult to obtain by conventional measurement techniques due to the large spatial variability in both soil moisture and snow depth and the limited number of locations within the catchment at which data are collected. At present, information from gamma snow surveys is used in a qualitative manner in the forecasting methodology. Information from the gamma snow surveys cannot be explicitly incorporated into the statistical approach used to forecast the runoff depth because the available historical record is too short to derive a valid relationship. Satellite microwave snow surveys have also become available in recent years and have likewise been used qualitatively to improve estimates of watershed conditions.

While the recent use of airborne gamma and satellite microwave snow surveys represent a positive addition to the data availability for flood forecasting in the Red River Valley, there have been other changes that have had a negative impact on forecasting capabilities. Of great concern has been the dramatic reduction in the hydrometric network within the basin. The hydrometric network provides the streamflow measurements that are used in the preparation of the operational forecasts. Reductions in the hydrometric network have occurred through cutbacks at both the federal and provincial level and could have serious impacts on the capability of accurately forecasting flood events in the Red River Valley. A second change in data availability is in the meteorological data, which are now provided mainly by automatic weather stations. Immediately following the transition to automatic weather stations, there were technological difficulties that negatively impacted the reliability of the data. Although these difficulties have apparently been largely resolved, users of the data understandably now have less confidence in the data and must decide which reports are reliable and which are not. This increased uncertainty associated with the meteorological data can result in significant flood forecasting errors if it is not possible to determine which of the data are accurate. A further concern is the sustainability of the near real-time meteorological reporting network. Due to Environment Canada's new policy of cost recovery, meteorological data are becoming more expensive and may become unaffordable.

New Technologies

There have been, and continue to be, new technologies developed that can be applied to the task of flood forecasting. Modern approaches to flood forecasting involve a large degree of automation such that the many routine and repetitive calculations are done by computer thus freeing the forecaster to concentrate on the interpretation and analysis of the forecasting results. The discussion of new technologies for flood forecasting will focus on two important aspects of the forecasting task; the prediction of the runoff depth and the estimation of water levels based on estimated streamflow values.

Runoff Depth Prediction

The statistical approach currently used by the Water Resources Branch to estimate the runoff depth could be replaced either with a more advanced statistical approach, such as nonparametric estimation, or with a runoff modelling approach. An example of a nonparametric estimation approach is an Artificial Neural Network (ANN). ANNs have proven to be particularly effective for making predictions when the input data are uncertain, or noisy, and the exact nature of the functional relationship between the input variables and the output variable is unknown. An ANN could therefore be an effective approach for the Red River application given the considerable uncertainty associated with the variables that are currently used in the regression relationships and the complex interactions between the variables that combine to form the runoff depth.

Greater improvements, however, are likely to come from the second approach mentioned above. A runoff modelling approach can readily incorporate information from the newly available airborne gamma snow surveys. This information should provide a better representation of the water content of the snowpack due to the enhanced characterization of the spatial variability of the snowpack that can be obtained. Runoff models of varying degrees of sophistication can be developed for forecasting applications. All runoff models, regardless of their complexity, essentially involve calculating a water balance for the catchment area. These models calculate the runoff that occurs as a result of water inputs, in the form of snowmelt and precipitation, and changes that occur to the catchment wetness. Recent research has explored the use of distributed models that are designed to provide a better representation of the spatial variability of the precipitation and snowmelt inputs and the catchment characteristics that affect the transition of precipitation and snowmelt into runoff. Distributed runoff models are often designed to operate with remotely sensed data in conjunction with the use of a geographic information system (GIS) to characterize the spatial variation of the inputs to the runoff process and the catchment characteristics that affect the generation of runoff. Distributed models are not, at present, widely used for the preparation of operational forecasts. However, simpler water balance models are routinely used elsewhere. For example, a water balance model forms a fundamental component of the forecasting approach used in the U.S. portion of the Red River Basin.

Estimation of Water Levels

The Water Resources Branch estimates the water level using a rating curve that relates the streamflow rate at a given location to the resulting water level. This is a common approach used for this task and it can be a very effective approach providing that the streamflow rates are within the range for which the rating curve is adequately defined and that the rating curve relationship is stable over time. However, this approach is often ineffective for large streamflow events that are of a magnitude beyond what has previously been recorded at the site. For large streamflow events, and indeed for smaller events as well, a better approach is to use a hydraulic model in order to more accurately represent the flow dynamics within the system. Models of this nature are complex and require a fair amount of calibration using observations from past flood events to provide good estimates of the water levels. A detailed characterization of the topography in the floodplain area is also required. This latter information is most useful if available in the form of a digital elevation model (DEM).

Although a dynamic hydraulic model is expensive to initially develop and to subsequently maintain, it is virtually the only viable approach for accurately describing the complex flow patterns and water levels that result when streamflow occurs outside of the main channel of a river. Accurately representing this phenomenon becomes particularly important for a river with a very flat floodplain, as is the case for the Red River Basin. An additional advantage of using a dynamic hydraulic model to describe the flow patterns is that it allows a better representation of the streamflow routing process than can be obtained with the Muskingum technique currently used by the Water Resources Branch. Hydrologic routing methods, such as the Muskingum technique, are generally not able to completely describe the streamflow dynamics of a complex river system, especially when streamflow occurs out of the main channel.

Performance Review for 1997

The forecasting results for 1997 were very good considering the unprecedented magnitude of the event and the limitations of the technology utilized to perform the forecasting. As noted above, the Water Resources Branch uses an experiential procedure that relies heavily on observations from past flood events. A statistically based runoff prediction approach will always have difficulty extrapolating to a flood magnitude beyond the range of events that have been used in formulating the relationships that form the basis for the predictions. There is also considerable uncertainty in the rating curves for the various locations along the river for the streamflow magnitude experienced during the flood. This means that accurate forecasts of the streamflow, which would not be easy to obtain, would not necessarily result in accurate forecasts of the water levels. Given the above factors, it would not have been at all unreasonable to expect that the forecasting results for 1997 would have been considerably worse than they were.

General Pattern of Forecasts

The pattern for the forecasting results was similar for much of the length of the Red River with the results south of Ste. Agathe being remarkably similar. Throughout the valley, the February and March flood outlooks indicated very high water levels were to be expected with the upper decile forecast indicating potential for flooding of a greater magnitude than any flood this century. The operational flood forecasts were first updated on April 10 following the blizzard in early April. Although the conditions in late March had generally been favourable, indicating a reduction in the flood risk, the additional moisture and the delay in the melt process that resulted from the blizzard led to an increase in the forecasted levels along the Red River. The forecasts for the median, or expected, levels increased from 1.0 to 1.5 feet while the upper decile forecasts increased by 0.5 feet. This had the effect of narrowing the forecast range at the various forecast locations. The forecasted levels did not change again until April 19 following flooding in Grand Forks. At this point in time, the median forecast was raised by 1.0 feet. On April 20, the forecasts were raised again following a crest in Grand Forks that was higher than expected. Both the upper decile and the median forecasts were raised by amounts of between 1.0 and 1.5 feet. On April 27, forecasted levels for portions of the Red River were again raised as a result of the peak water level at Emerson coinciding with the occurrence of the peak from the Manitoba tributaries. Both the median and upper decile forecasts were raised by 0.5 feet from Ste. Agathe to the floodway entrance. The availability of a flow measurement at Ste. Agathe resulted in a lowering of the forecasted level on April 29 for both Ste. Agathe and St. Adolphe while the forecast at the floodway entrance was raised slightly. Finally, on May 1 the forecasted levels for St. Adolphe and the floodway entrance were raised as the flood peak drew near.

Figure 1 provides a summary of the forecasting results for selected locations along the Red River. The bar graphs displayed in Figure 1 represent the difference between the median forecast and the actual water levels at selected locations for each of the forecast dates. Negative values on the graph represent an under prediction of the actual water level while positive values indicate that the water level was forecasted to rise higher than it actually did. As can be seen from the figure, the forecast errors generally decrease in magnitude for the later forecast periods. It can also be observed that the magnitude of the forecast error tended to increase for the more northerly locations with the maximum forecast error occurring immediately above the floodway inlet.

Further observations on the forecasting results for individual locations within the Red River Valley are presented below. The observations focus on both the forecasts of the magnitudes of the water levels and on the timeliness of the forecasts. Both of these dimensions of the flood forecasts are important in order for potentially affected individuals to adequately prepare for the rising floodwaters. Forecasts of the water level provide an indication of the amount of protection required from the floodwaters while the timing of the forecasts indicates the amount of advance warning that was provided.

Emerson and Morris

Forecast results for Emerson and Morris are representative of results for the south part of the Canadian portion of the Red River. At both Emerson and Morris, the actual peak level was within the forecast range given in the initial flood outlook produced in late February. The median forecast released on April 10 was within 0.5 feet of the actual peak for Emerson and within 1.0 feet at Morris. The updated forecasts of April 19 were essentially the same as the actual peaks observed. Revisions to the forecasts on April 20 resulted in a slight over prediction of the peak level. These results can be seen from Figures 2 and 3, which show the actual water levels as well as the median and upper decile forecasts for Emerson and Morris, respectively.

Table 1 presents results relating to the timing of the forecasts. Shown for several locations along the Red River is the date on which a forecast of the timing of the peak was made, the forecasted date of the peak, and the actual date of the peak flow at the location. For both Emerson and Morris, the results are seen to be quite good. The date of occurrence of the peak water level was predicted fairly accurately as of April 19, providing advance warning of about a week at Emerson and slightly longer at Morris. The update on April 23 provided an exact estimate for Emerson but predicted a later peak at Morris than what actually occurred.

The results in the south part of the Canadian portion of the Red River were thus extremely good. Both the peak water levels and the time of occurrence of the peak were accurately forecasted well in advance of the actual events. The slight over prediction of the water level following the flooding in Grand Forks is understandable given the uncertainties associated with the information coming from the U.S. portion of the basin.

Ste. Agathe

At Ste. Agathe, the actual peak level was above the upper decile of the flood outlooks provided in February and March. However, the actual peak level was predicted on April 20, nine days in advance of the peak. The upper decile flood level predicted after the April blizzard was also within 0.5 feet of the actual peak. Thus there was advance warning of high water levels in the Red River at Ste. Agathe. The forecast revision of April 27 resulted in a forecasted level that was higher than was actually experienced, however this was revised downwards on April 29 prior to the actual crest at this location. These results can be seen in Figure 4.

Table 1 shows the forecasts of the timing of the flood to be quite accurate for this location. Forecasts as early as April 19 were predicting the date of occurrence of the peak to within a day. The poorest prediction in fact occurred on May 1, the date of the peak, when the peak was predicted to occur on May 4.

The greatest difficulties with forecasting at Ste. Agathe likely arose due to overland flow that ultimately resulted in the town flooding from the west on April 29. This was not predicted in advance since a flood of this magnitude had not been experienced before and thus overland flow of this nature had not previously been observed. The current forecasting techniques are not capable of predicting complex flow patterns out of the main banks of the river and thus did not provide warning of the potential for flooding of Ste. Agathe from the west.

St. Adolphe

The forecast results for St. Adolphe are quite similar to those at Ste. Agathe. The initial flood outlook for this location was again too low with a median forecast about 4 feet lower than the observed peak. However, an accurate forecast of the crest elevation was obtained on April 20, almost two weeks in advance of the occurrence of the peak. This value was subsequently revised upwards and then downwards before being revised to a level essentially corresponding to the actual peak magnitude. These results are shown in Figure 5.

The timing of the peak was also predicted quite well as can be seen from Table 1. An estimate of the date of occurrence made on April 19 was within two days of the actual peak while subsequent updates provided even closer estimates of the date of the actual peak, which occurred on May 3.

Above the Floodway Entrance

The peak water level was not well predicted above the floodway entrance (see Figure 6). The actual flood peak was above all of the upper decile forecasts even for forecasts made four days prior to the peak flow. The forecasts did not predict the final rise in the water level that commenced on April 30 at the time of the final raising of the floodway gates. Two possible reasons for the poor forecasting results at this location are suggested. Firstly, it is possible that the impact of the floodway operation was not adequately addressed when forecasts were made for this location. In particular, it appears as though the decision to operate the floodway to produce water levels above natural was not reflected in the forecasts. Secondly, the uncertainty in the rating curve is likely to be greater for this location than elsewhere in the valley due to the complex flow patterns that result as water comes into a comparatively narrow cross-section from the vast "Lake Morris" to the south.

The timing of the peak, in contrast, was forecasted fairly well (see Table 1). A forecast on April 23 was essentially correct as to the date of occurrence of the flood peak. Subsequent updates to the forecasted timing of the peak were given as a range that included the actual date of the peak, May 4.

City of Winnipeg

Forecasts for the City of Winnipeg at the James Avenue station are depicted in Figure 7. The initial water level outlooks from early spring were considerably lower than the actual levels experienced. Following the April blizzard, the upper decile forecast was raised considerably, while the increase in the median forecast was considerably smaller. It is not obvious why the median forecast was not raised further at this time, as it was elsewhere along the river. This discrepancy can be seen in the results presented in Figure 1. The actual peak level was slightly above the upper decile forecast made on April 10 although the weather conditions following April 10 (generally favourable) should have resulted in a water level closer to the lower decile than the upper decile. The median forecast was raised more than 3 feet on April 20 although even this forecast was slightly low in comparison to the actual peak. Even as the flood peak approached, there was a slight under prediction of the peak level for James Avenue.

In contrast to the magnitude of the peak, the timing of the peak at James Avenue was predicted fairly well. Table 1 reveals that the prediction on April 19 was quite accurate with subsequent updates providing estimates that were either at or close to the actual value.

Figure 8 shows the errors in the median forecasts for four sites within the City of Winnipeg. The results reveal that the median forecasts represented a considerable under prediction of the actual water levels particularly for the south of the city. Note that the earliest forecast results shown are for April 10, following the April blizzard. The magnitude of the under prediction, as late as April 19, is somewhat surprising. It is fortunate that the City of Winnipeg was preparing for the upper decile forecast water level and not for the water level associated with the median forecast.

Grande Pointe

Forecast results for Grande Pointe are shown in Figure 9. The initial flood forecasts for this location were of the order of 8 feet too low. This can also be seen on the graph of errors in the median forecasts depicted in Figure 10. It should be noted that April 16 was the first date on which forecasts were published for Grande Pointe. Updates to the forecasted levels seemed to rise in response to observed rises in the level of the water at Grande Pointe. It appears that the water levels in Grande Pointe were affected by the water levels at the floodway entrance (see additional curve on Figure 9 depicting the water level upstream of the floodway entrance). The original forecasts for this location do not appear to have taken this influence into account.

The timing of the peak at Grande Pointe was also not well predicted, as can be seen in Table 1. The initial forecasts predicted a peak to occur earlier than actually occurred. As time went by, the predicted timing of the peak was further delayed even on the day of the actual peak. It would appear again that the initial predictions did not anticipate Red River water arriving in the Grande Pointe area.

The poor forecasting results for Grande Pointe left the people in this area ill-prepared for the flood event. The initial forecasts were much too low indicating that very little protection was required for residences in this area. In fact, the water levels rose to as much as 8 feet above the level indicated in the initial forecasts. The problem with the prediction of the timing of the flood event further emphasizes the need for revisions to the forecasting procedures used at this location.

Summary of Comments from Public Meetings

A number of concerns that relate to forecasting were raised at the public meetings. These concerns were heard mainly from residents in the area immediately upstream of the floodway and from residents of the Grande Pointe area. The most commonly occurring complaint related to a lack of sufficient preparation time following a forecast in order for affected individuals to adequately protect their property and possessions. The Commission heard that advance warning of the loss of access roads is essential information for residents in the potential flood area. There are locations in this area where access to properties was lost well in advance of the arrival of the peak water level. This meant that many individuals were not able to protect their properties to the desired level in the time that was available to them. It is apparent that for some areas, the peak water level and when it will occur is not the only forecast information that is required for adequate flood preparations.

Many residents felt that the floodway operation both impacted the water levels that were experienced and also resulted in inaccuracies in the forecasts of water levels. The rate of rise of the water level was reported by residents of the area to be greater than that experienced during past flood events. This had a negative impact on the ability of residents to complete their flood preparations in a timely manner.

Residents of the Grande Pointe area were extremely disappointed in the forecasts for their area. As indicated above, early forecasts for this area were very low resulting in what turned out to be poor decisions being made by many residents. The initial advice given to many residents was to build a dike of one or two feet primarily for their own reassurance. The implication was that the dikes would likely remain dry. Many of these residents ultimately required substantially higher dikes that could not be readily built on top of the original dikes that were constructed. The initial advice that many of these people were given was poor and the result was that it was virtually impossible for many of these people to construct the required flood protection in time.

The Commission also heard of confusion regarding the actual forecast levels for some portions of the flood area. While forecasts are calculated for a defined set of locations along the Red River (i.e., Ste. Agathe, St. Adolphe, etc.) there is a need for forecast information at other locations as well. Forecast information at these other locations (an example would be the Red River Drive or Marchand Road areas upstream of the floodway inlet) must be derived from the forecast information for the defined forecast points. It appears as though the dissemination of this information did, on occasion, lead to some confusion for residents of the affected areas.

Residents of the valley expressed concerns with regard to the potential of the Water Resources Branch to continue to provide accurate forecasts for the Red River. Concerns were raised regarding the adequacy of the hydrometric network to provide the information that is essential for the forecasting task. Residents questioned whether or not the Water Resources Branch is using the latest technology in the forecasting procedures currently in place. Finally, concerns were expressed regarding the adequacy of the staffing level assigned to flood forecasting.

Recommendations

The following recommendations are made based on a review of the forecasting results, discussions with staff from the Water Resources Branch and information received from residents of the Red River Valley.

1. The number of staff dedicated to flood forecasting should be increased. It is inconceivable that such a fundamentally important task would be handled by a single, senior staff member, with at best limited back-up capabilities. All residents of the Red River Valley, and of the province of Manitoba, are in a very vulnerable position as a result of this situation. Given the heuristic nature of the forecasting procedures, and the resulting level of expertise required to prepare forecasts, it is essential that new staff be hired now to ensure continuity in this essential and challenging activity.

2. Efforts must be made to preserve the existing hydrometric network to ensure that the information required for flood forecasting is available when it is next needed for a major flood. Ideally, the hydrometric network should be restored to levels that existed as recently as five years ago. The importance of hydrometric data for flood forecasting cannot be over emphasized especially in the downstream portions of a river system, such as the Canadian segment of the Red River, where forecasts are largely based on observations of streamflow at upstream locations.

3. Efforts should be made to increase the level of coordination between the U.S. forecasting centre and Canadian forecasting efforts. It is essential for the Canadian forecasters to receive timely information and data given the importance of information on conditions in the U.S. portion of the basin to the forecasts in Manitoba. Assigning a person to work with the U.S. forecasters during flood events would ensure that the information received by the Manitoba forecasters is both timely and accurate.

4. The forecasting methodologies currently used require updating. This will be necessary in part due to changes in the availability of data and in the type of data that are available. In addition, the Flood of 1997 has dramatically demonstrated the difficulties associated with predicting water levels that will result when overland flow occurs. It is unlikely that accurate forecasts of this flow regime can be obtained using the procedures currently in place. The use of a runoff model to predict the depth of runoff and a dynamic hydraulic model to predict the water levels has the potential to greatly enhance the forecasting capabilities. The development of a dynamic hydraulic model is envisioned as a part of the study plan of the Red River Basin Task Force of the International Joint Commission. The Water Resources Branch has previously investigated the use of hydrologic modelling for forecasting. Both of these efforts should be adequately supported.

5. The Water Resources Branch needs to update the technology used within the Hydrologic Forecast Centre. One way that new technologies can be introduced into an organization is through hiring recent graduates who have a strong background in the use of new technologies. The new staff members can then contribute to the technology transfer process as they work with staff members who, while having many years of practical experience, may not have received the same exposure to the latest theoretical developments. Unfortunately, the Water Resources Branch has not hired many recent graduates so this type of technology transfer has not been possible. A second option for technology transfer is for an organization to become involved in Research and Development activities that allow it to explore the options for utilizing new technologies within its operations. This can be done in-house, although this may be difficult given the staff profile of the branch, or can be done through the university system. The latter option should be given serious consideration.

6. A forecasting system needs to be developed for the Grande Pointe area. At present, forecasts for Grande Pointe are obtained based on forecasts for the Seine River at the Prairie Grove gauging station location. This year, the forecasts were woefully inadequate. It is essential that forecasts be made for Grande Pointe that consider the potential for Red River water to contribute to the flooding through overland flow. Similar modelling approaches are required for Ste. Agathe and for the area upstream of the floodway entrance.

7. Further consideration should be given to the manner in which forecast information is disseminated. Inclusion of forecast information on the Internet during the 1997 flood event was a valuable innovation that should be continued for other flood years. However, not every resident in the Red River Valley has access to the Internet, particularly as the flood peak approaches. Effective means of communicating flood forecasts to all individuals in the valley must be in place well in advance of the arrival of the flood peak. It is particularly important that people have ready access to site-specific flood forecast information so that individuals are aware of the conditions that they are likely to experience. This would likely necessitate interpretation of the forecast results for individual locations by staff with local experience.

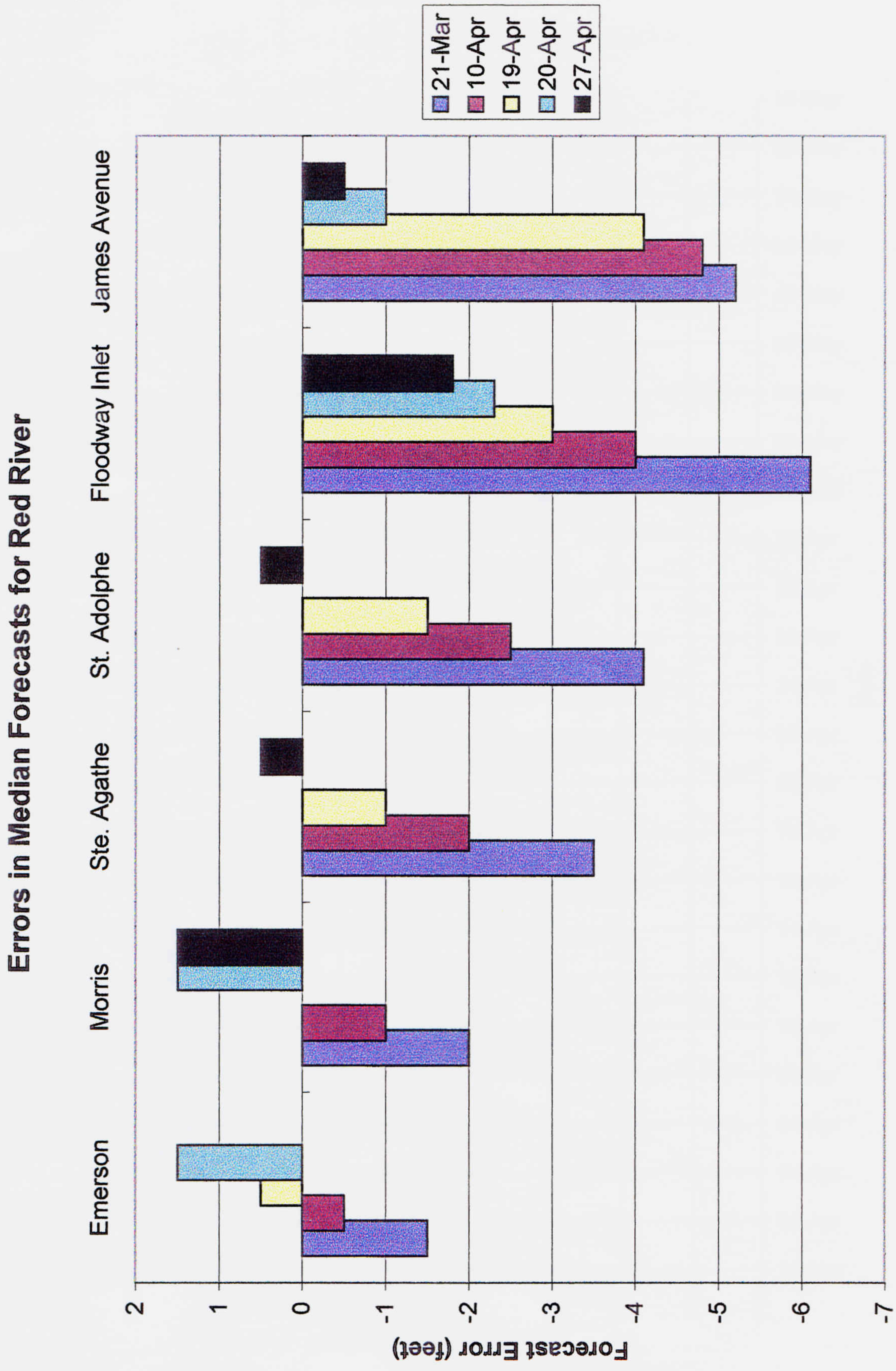
8. The forecast information available to people should be expanded to facilitate emergency planning in different localities. The peak water level is undoubtedly the single most important piece of information required by residents of the valley. However, the date on which access to different areas will be lost due to roads being under water is also very important. The Commission heard of many individuals who thought they had more time to prepare for the coming floodwaters than they actually did. It must be realized that many residents assume that the progression of a flood will be similar from one year to the next and as such they rely on past experiences in their preparations for a flood event. If these residents had been told that the rate of rise for the 1997 flood would be greater than that experienced in previous floods, they may have reacted differently.

9. Greater public education is needed to enhance the understanding of the concept of a lower decile, median and upper decile forecast. During the 1997 flood event, the City of Winnipeg formulated contingency plans to handle the upper decile flood event. This turned out to be a wise move. Some other municipalities did not develop the same type of contingency plan. It may be prudent to either provide one forecast value or to ensure that users understand and know how to use the forecast range that is currently given.

FORECASTS OF THE TIMING OF THE PEAK WATER LEVEL

Location	DATE OF FORECAST	FORECASTED DATE FOR PEAK	ACTUAL DATE FOR PEAK
Emerson	April 10 April 19 April 23	Late April April 25 April 27 - 28	April 27
Morris	April 10 April 19 April 23	Late April April 29 May 2	April 29 - 30
Ste. Agathe	April 10 April 19 April 23 April 29 May 1	Early May April 30 May 3 April 30 May 4	May 1
St. Adolphe	April 10 April 19 April 23 April 29 May 1	Early May May 1 May 4 May 1 - 4 May 4 - 5	May 3
Above Floodway	April 10 April 19 April 23 April 29 May 1	Early May May 1 May 5 May 1 - 5 May 4 - 5	May 4
James Avenue	April 10 April 19 April 23 April 29	Early May May 2 May 5 May 1 - 3	May 2 - 4
Grande Pointe	April 16 April 23 April 25 April 29 April 30 May 1 May 2 May 4	Late April Early May April 26 - 27 April 29 - May 3 May 1 - 3 May 1 - 2 May 4 - 5 May 5	May 4

Figure 1



Errors in Median Forecasts for Red River
Emerson
Morris
Ste. Agathe
St. Adolphe
Floodway Inlet
James Avenue
21-Mar
10-Apr
19-Apr
20-Apr
27-Apr
2
1
0
-1
-2
-3
-4
-5
-6
-7
Forecast Error (feet)

Figure 2

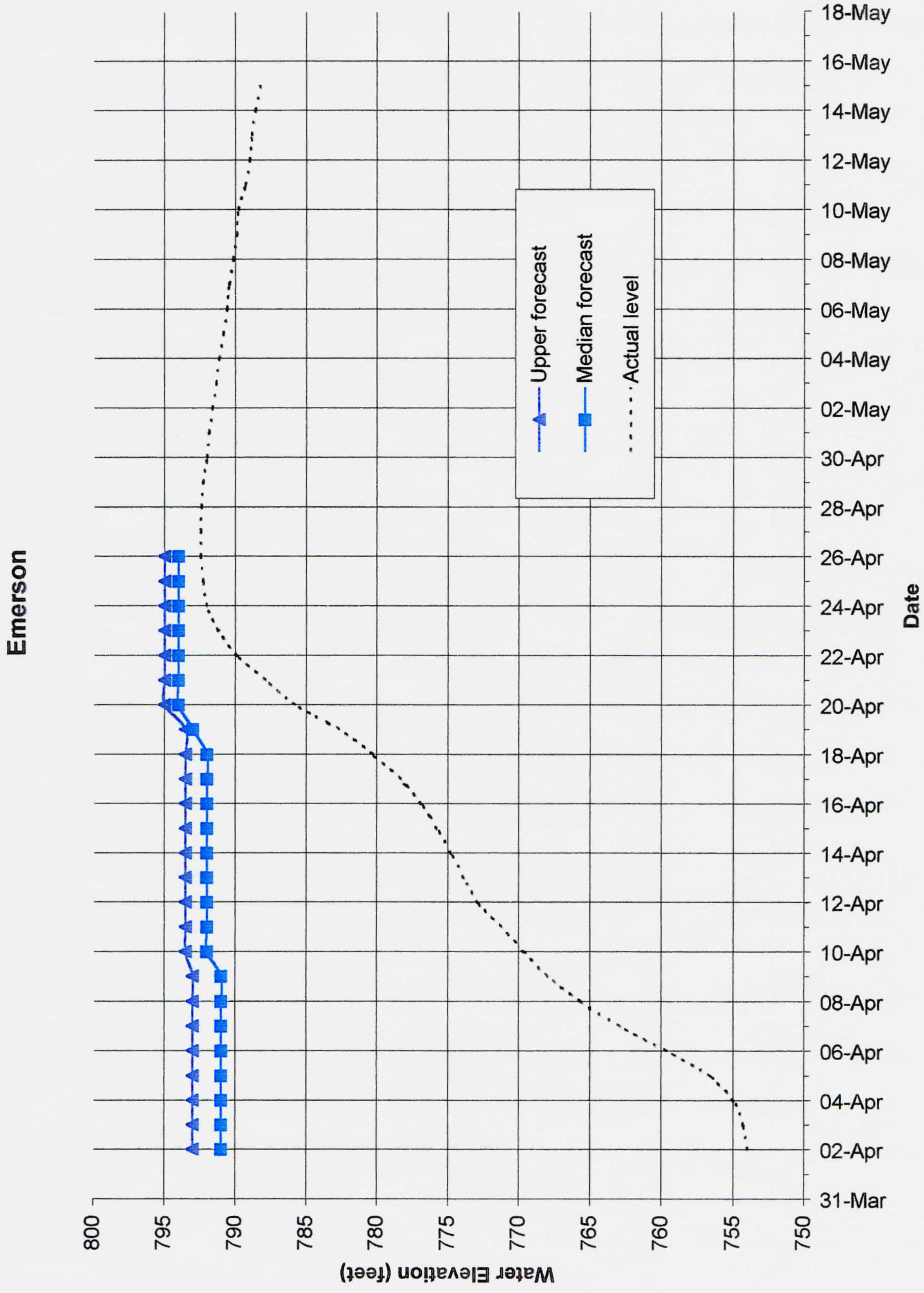

Emerson
Upper forecast
Median forecast
Actual level
Water Elevation (feet)
800
795
790
785
780
775
770
765
760
755
750
Date
31-Mar
02-Apr
04-Apr
06-Apr
08-Apr
10-Apr
12-Apr
14-Apr
16-Apr
18-Apr
20-Apr
22-Apr
24-Apr
26-Apr
28-Apr
30-Apr
02-May
04-May
06-May
08-May
10-May
12-May
14-May
16-May
18-May

Figure 3

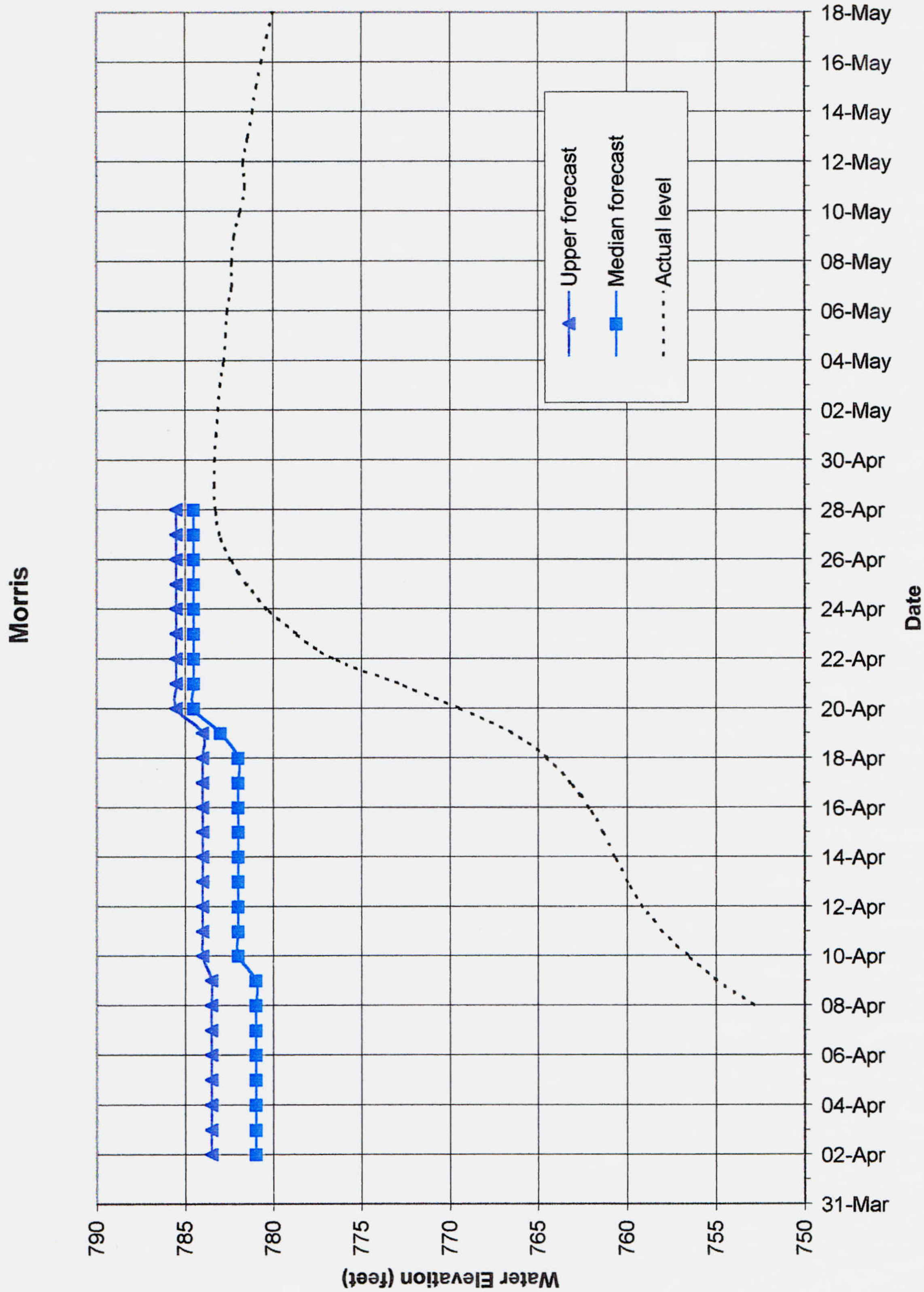

Morris
Upper forecast
Median forecast
Actual level
Date
Water Elevation (feet)
790
785
780
775
770
765
760
755
750
31-Mar
02-Apr
04-Apr
06-Apr
08-Apr
10-Apr
12-Apr
14-Apr
16-Apr
18-Apr
20-Apr
22-Apr
24-Apr
26-Apr
28-Apr
30-Apr
02-May
04-May
06-May
08-May
10-May
12-May
14-May
16-May
18-May

Figure 4

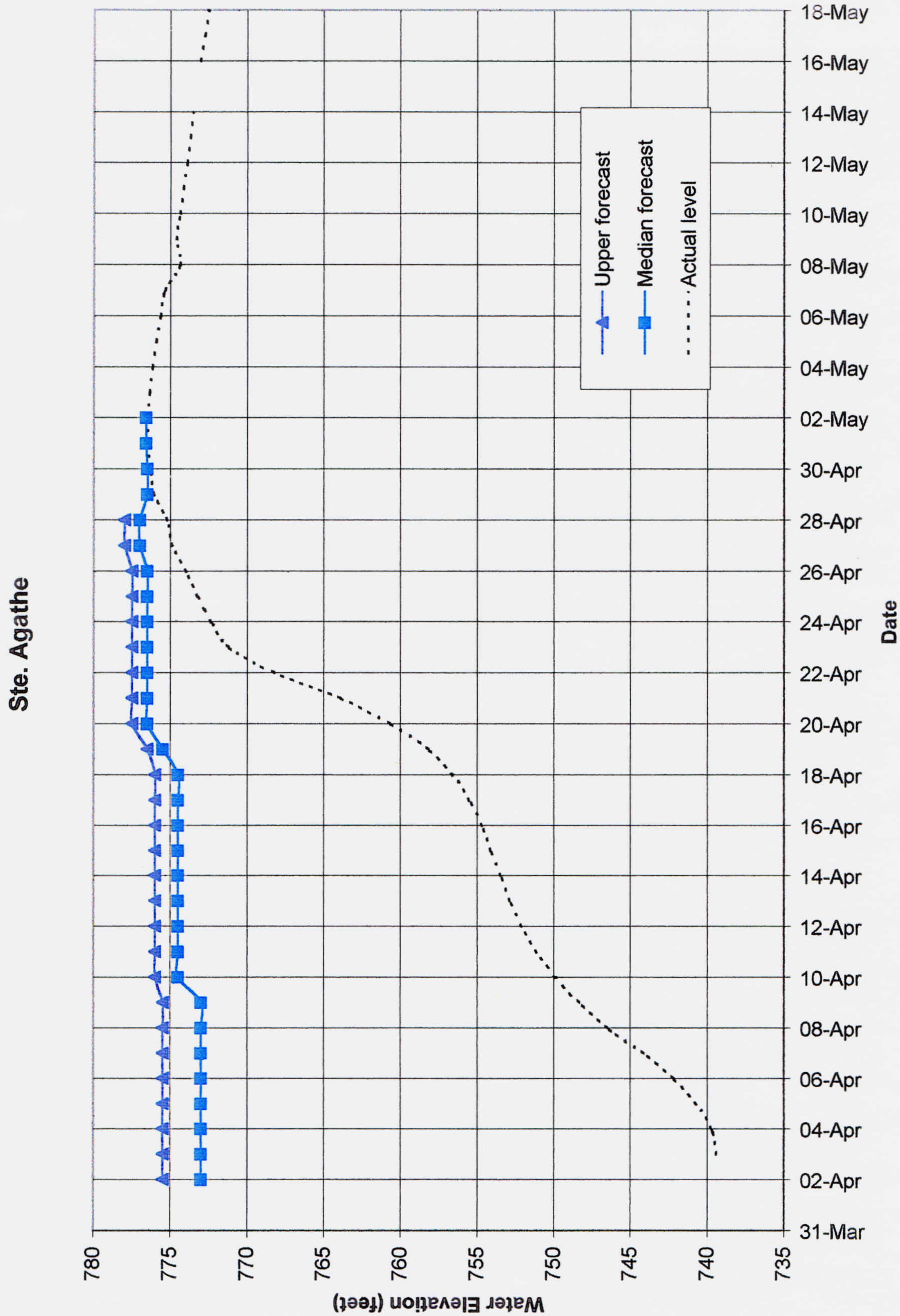

Ste. Agathe
Upper forecast
Median forecast
Actual level
Water Elevation (feet)
780
775
770
765
760
755
750
745
740
735
Date
31-Mar
02-Apr
04-Apr
06-Apr
08-Apr
10-Apr
12-Apr
14-Apr
16-Apr
18-Apr
20-Apr
22-Apr
24-Apr
26-Apr
28-Apr
30-Apr
02-May
04-May
06-May
08-May
10-May
12-May
14-May
16-May
18-May

Figure 5

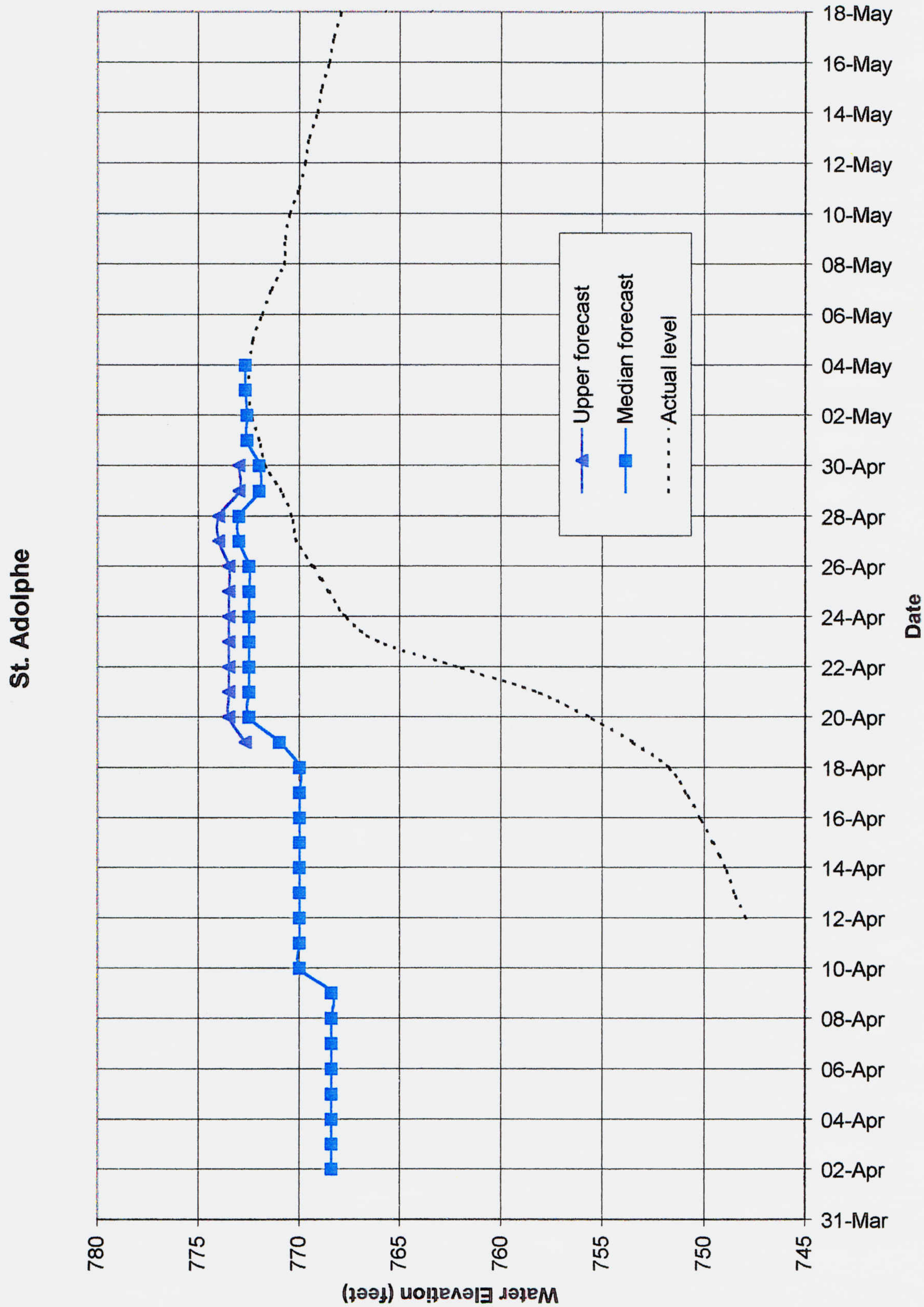

St. Adolphe
Upper forecast
Median forecast
Actual level
Date
Water Elevation (feet)
780
775
770
765
760
755
750
745
31-Mar
02-Apr
04-Apr
06-Apr
08-Apr
10-Apr
12-Apr
14-Apr
16-Apr
18-Apr
20-Apr
22-Apr
24-Apr
26-Apr
28-Apr
30-Apr
02-May
04-May
06-May
08-May
10-May
12-May
14-May
16-May
18-May

Figure 6

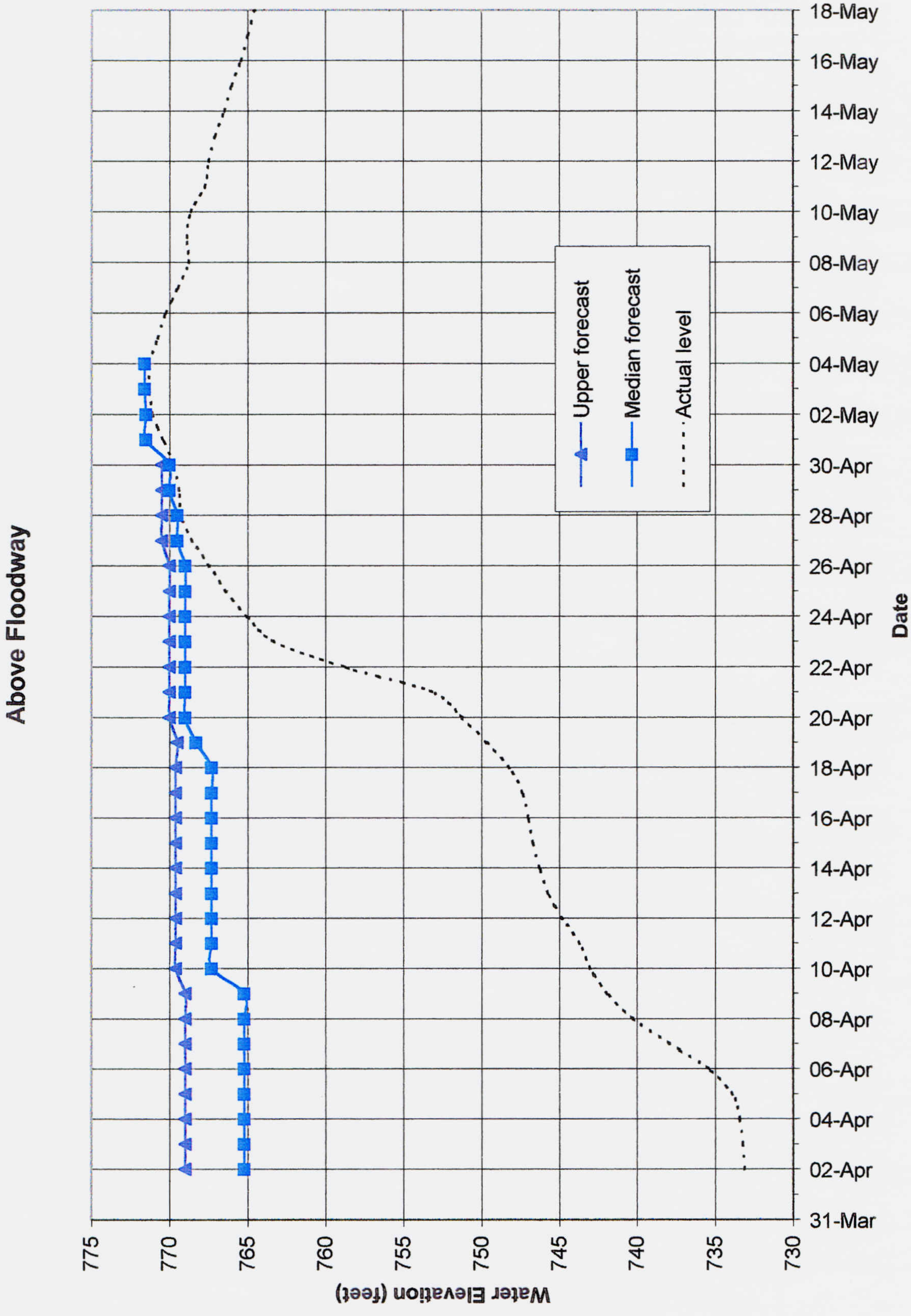
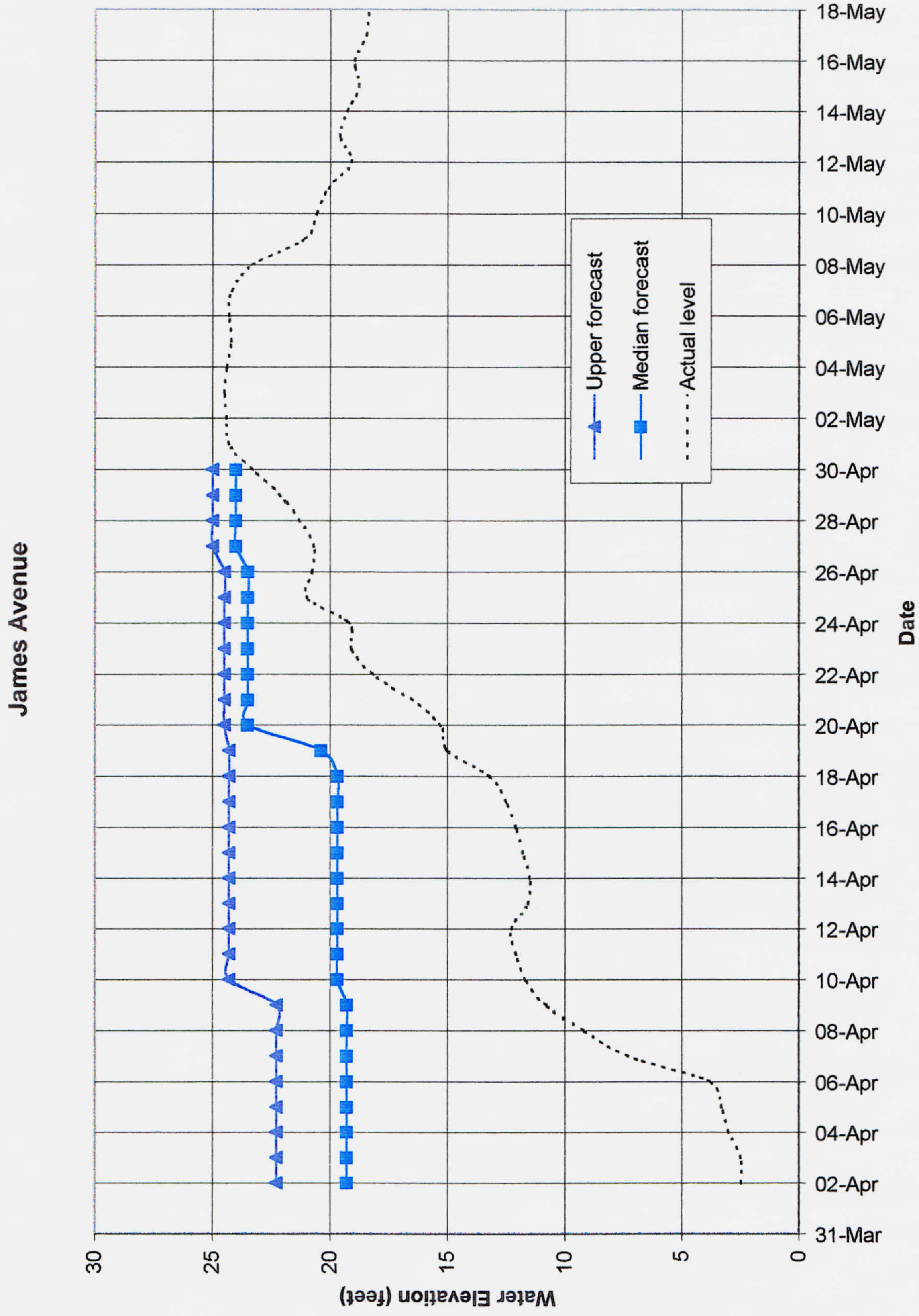

Above Floodway
Upper forecast
Median forecast
Actual level
Water Elevation (feet)
775
770
765
760
755
750
745
740
735
730
Date
31-Mar
02-Apr
04-Apr
06-Apr
08-Apr
10-Apr
12-Apr
14-Apr
16-Apr
18-Apr
20-Apr
22-Apr
24-Apr
26-Apr
28-Apr
30-Apr
02-May
04-May
06-May
08-May
10-May
12-May
14-May
16-May
18-May

Figure 7



James Avenue
Upper forecast
Median forecast
Actual level
Water Elevation (feet)
Date
30
25
20
15
10
5
0
31-Mar
02-Apr
04-Apr
06-Apr
08-Apr
10-Apr
12-Apr
14-Apr
16-Apr
18-Apr
20-Apr
22-Apr
24-Apr
26-Apr
28-Apr
30-Apr
02-May
04-May
06-May
08-May
10-May
12-May
14-May
16-May
18-May

Figure 8

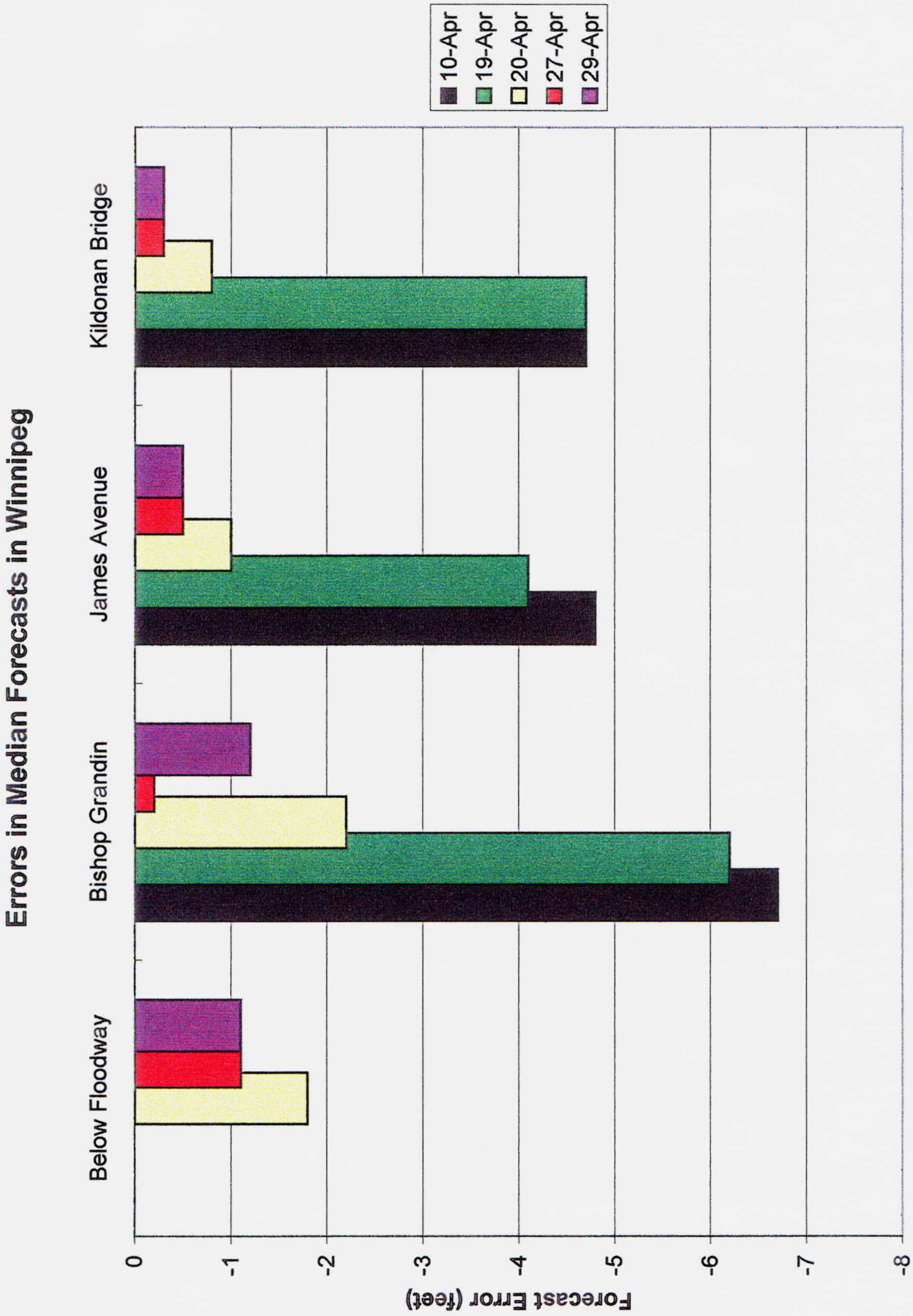

Errors in Median Forecasts in Winnipeg
Below Floodway
Bishop Grandin
James Avenue
Kildonan Bridge
10-Apr
19-Apr
20-Apr
27-Apr
29-Apr
0
-1
-2
-3
-4
-5
-6
-7
-8
Forecast Error (feet)

Figure 9

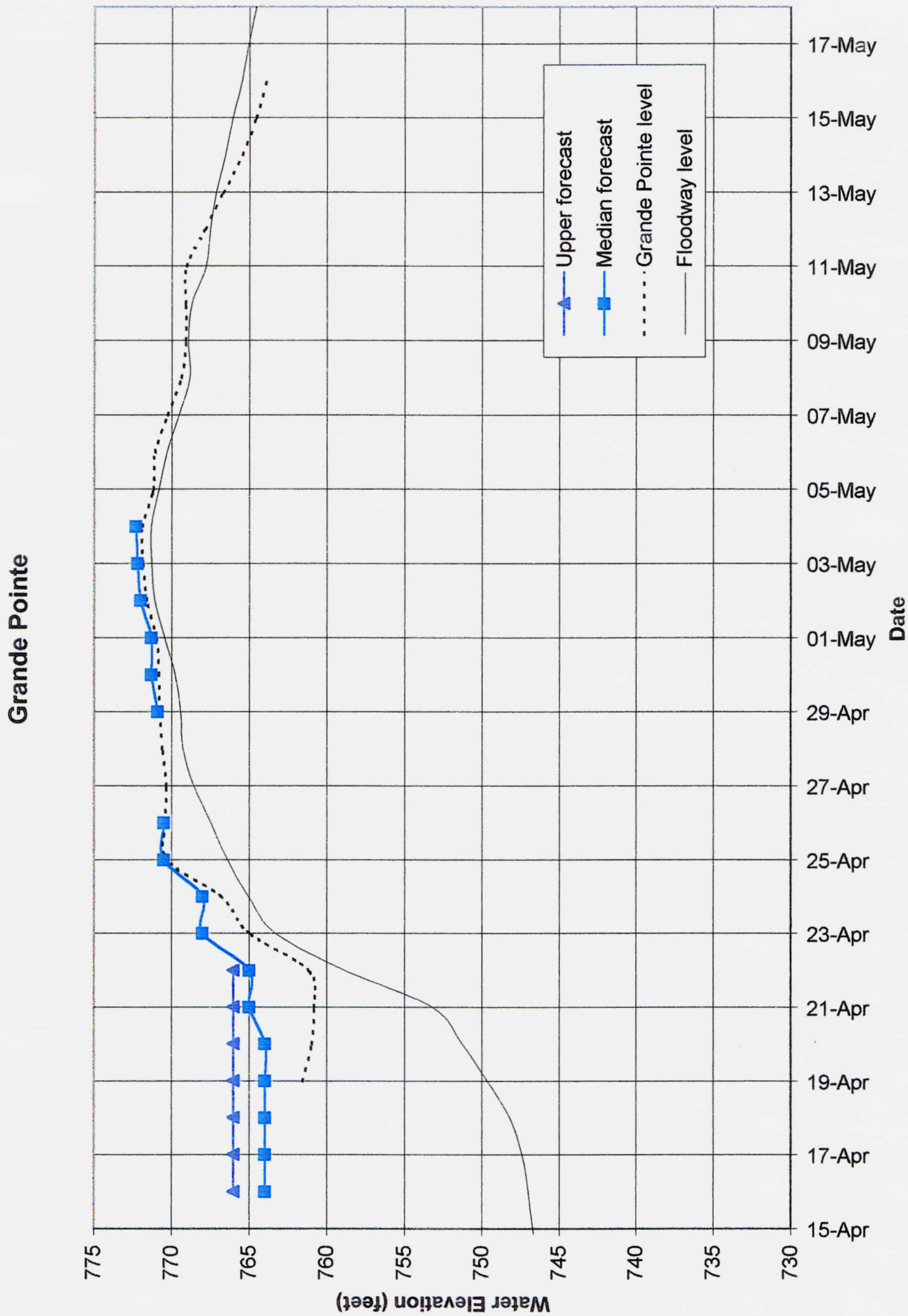
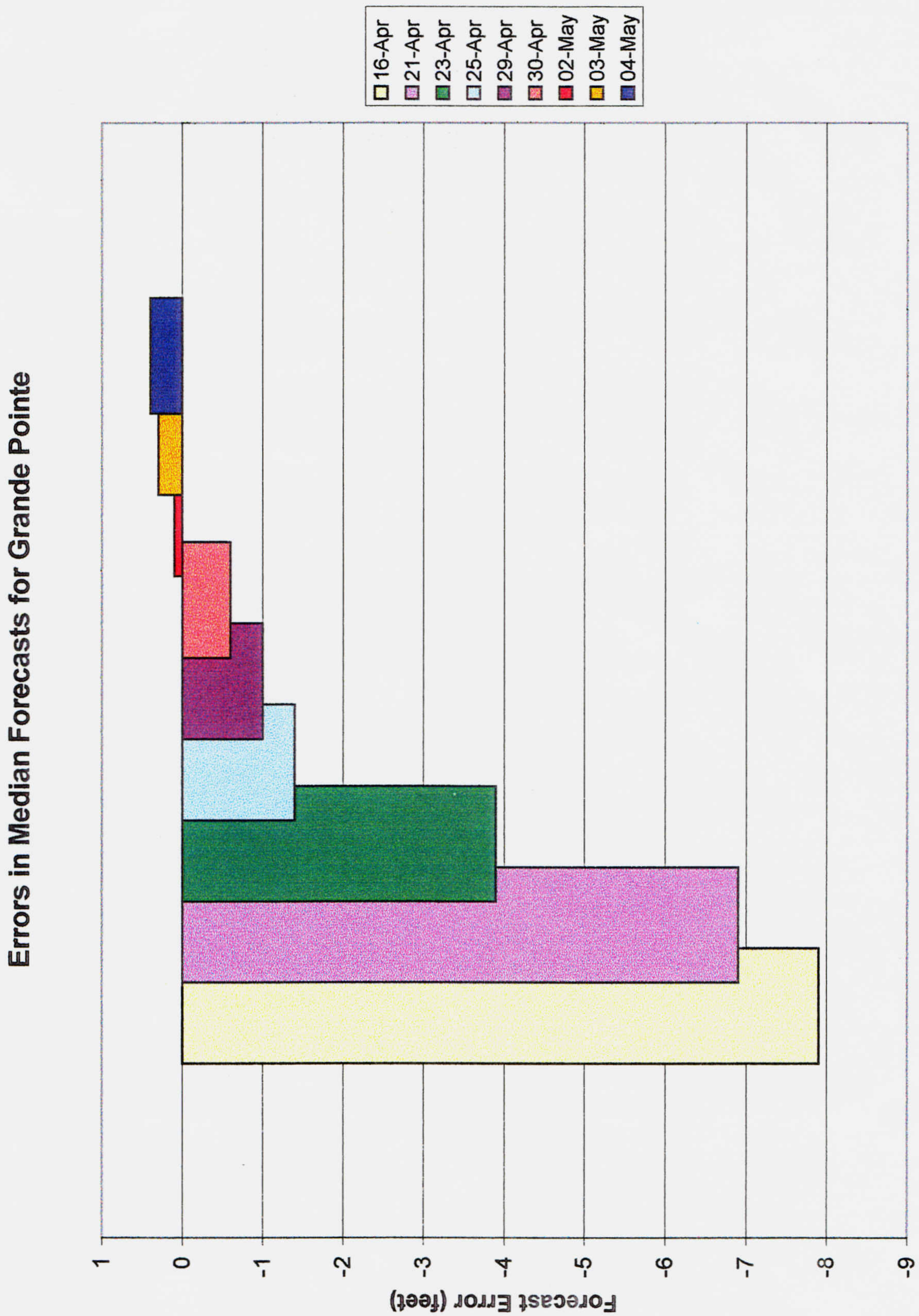

Grande Pointe
Upper forecast
Median forecast
Grande Pointe level
Floodway level
Water Elevation (feet)
775
770
765
760
755
750
745
740
735
730
Date
15-Apr
17-Apr
19-Apr
21-Apr
23-Apr
25-Apr
27-Apr
29-Apr
01-May
03-May
05-May
07-May
09-May
11-May
13-May
15-May
17-May

Figure 10



Errors in Median Forecasts for Grande Pointe
16-Apr
21-Apr
23-Apr
25-Apr
29-Apr
30-Apr
02-May
03-May
04-May
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
Forecast Error (feet)