MUNICIPAL WATER INFRASTRUCTURE CAPITAL IMROVEMENT PLANNING UNDER UNCERTAINTY: DECISION CHALLENGES

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ABSTRACT

The City of Portland Bureau of Water Works (PWB) has supplied domestic water to Portland-area residents since 1885. It is the largest supplier in Oregon, and providing both retail and wholesale water to nearly 840,000 people. Portland's primary source of supply, the Bull Run Reserve, is an unfiltered water source. The PWB faces a wide variety of challenges and uncertainties in the new millennium. These uncertainties arise from several principal sources: current federal regulatory requirements and potential future changes that affect water quality standards; treatment and the Endangered Species Act (ESA); conservation; decisions by current and potential wholesale customers about whether to obtain supply from Portland or elsewhere; decisions about where to obtain supply in the future and whether groundwater will be a basic component of the future supply or will be reserved only for emergencies; supply reliability; regionalization of the Portland's supply system; demand forecasts; and the impact of climate variability. In an attempt to better understand these uncertainties, and develop a decision framework for an integrated strategy that will guide the timing and cost implications of the PWB's capital improvement programs (CIP), the PWB has commissioned a number of technical studies over the past 5 years. The purpose of this paper is to discuss the decision process and the factors that have influenced and shaped the integration of the results of the studies, including the recently completed Climate Variability Study. The paper will also discuss the decision support systems developed by the PWB to facilitate the decision-making process.

1 PORTLAND'S BACKBONE WATER SYSTEM

The Portland Water Bureau (PWB) has served the city of Portland, Oregon, and its outlying areas since 1885. Today, the system serves some 840,000 people and delivers an average of 110 million gallons per day (mgd). The PWB obtains its water from two primary sources, the Bull Run watershed, and the Columbia South Shore Wellfield (CSSW). Two major dams, Dam 1 and Dam 2, are located on the Bull Run River. Dam 1 was constructed between 1927 and 1929 and currently impounds approximately 9.9 billion gallons (BG). Dam 2 was constructed in the early 1960s and holds approximately 6.8 BG. The total available water supply from the reservoirs is 10.2 BG. There is also a natural lake (Bull Run Lake) in the watershed from which 1 BG of water can be obtained on an emergency basis (see Figure 1).

The CSSW was constructed in the early 1980s as an alternative, emergency source of water. The wellfield can produce up to 90 mgd and has been used thirteen times. However, it was used for an extended period only once during a drought event in 1987. This was the most severe drought in Portland's recent hydrologic history. The PWB has three major in-town storage reservoirs, Powell Butte, Mt. Tabor, and Washington Park. These combine for a total of 177 million gallons

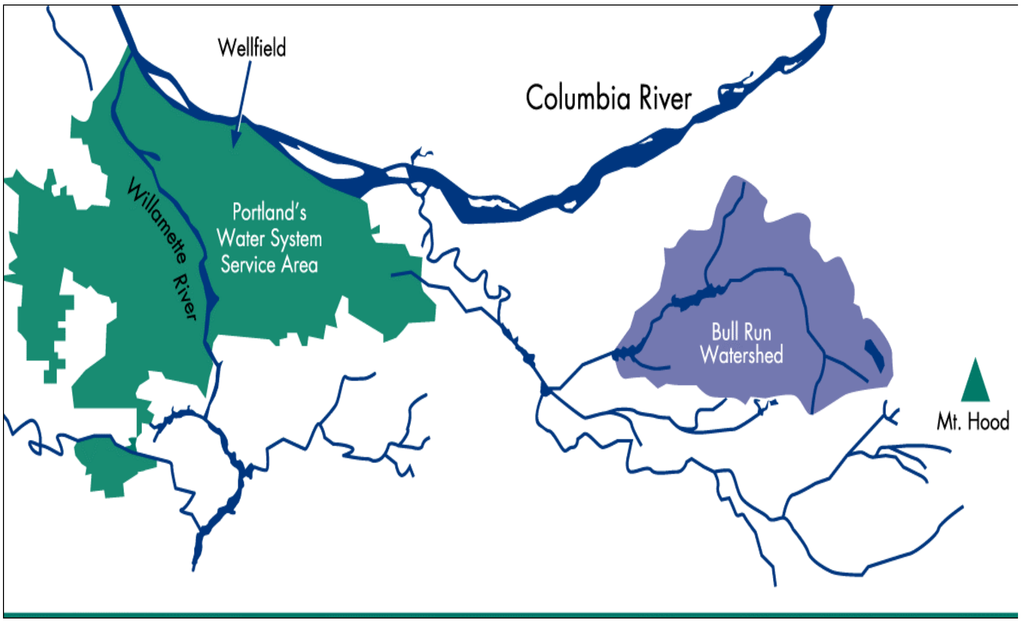

Figure 1. Water system vicinity map

The PWB has contracts with 19 water purveyors in the Portland metropolitan area, serving some 300,000 customers. These customers account for 20% of the annual water sales and 40% of the annual water demand.

The PWB currently provides a pH adjustment that minimizes metal corrosion in plumbing and chloramines to disinfect the water. It is likely that filtration will be required for Bull Run water in the future. In addition to these drinking water concerns, the National Marine Fisheries Service (NMFS) listed Columbia River steelhead trout as a threatened species under the Endangered Species Act in 1997 and Chinook salmon in 1999. Because of these listings, there is considerable interest in the fisheries resources in the Bull Run River. Studies are underway to determine the impacts of increased fish flows in the river. A significant portion of the PWB's 10.2 BG reservoir storage may be needed for fish flows.

Parts of the Portland supply system are over a century old. The water supply system for Portland began in 1851. Residents drew water from wells until the mid-1850s, when water pollution triggered the need for a public water supply. Elements of the Bull Run system were originally constructed in 1894, with enlargement in 1911, dam construction in 1929 and 1962, and the ground water system going online in 1984. Throughout the system's history, the natural hazards that have impacted its operation have been primarily high turbidity in the watershed and landslides along the conduits.

2 WATER SUPPLY PLANNING STUDIES

In 1989 Portland regional water providers (now known as the Consortium) began discussing future regional water supply alternatives, regional transmission options, and governance issues. In 1996 the group completed its Regional Water Supply Plan (RWSP). This study investigated a number of specific issues including the construction of new supply sources and regional transmission lines, and programmatic conservation. The new supply sources investigated included:

1) filtering Bull Run water, which would provide an additional 2.7 BG of water for water supply;

2) increasing the elevation of Dam 2, which would increase water supply storage by 2 BG;

3) constructing a third dam in the Bull Run Watershed, which would provide 19 BG of water;

4) modifying Dam 1's gates, which would provide 200 million gallons;

5) utilizing groundwater in the Bull Run basin, and;

6) increasing the groundwater yield of the CSSW to 100 mgd.

In 1998, Portland initiated its own regional water supply study, the Infrastructure Master Plan (IMP). Its primary goals were to define specific alternatives for the Portland system that fit into the broad planning alternatives defined by the RWSP and to improve the PWB's ability to quickly and accurately evaluate system improvement alternatives. Other goals of the study included:

1) providing water system operating and cost data for upcoming wholesale contract renegotiations;

2) examining emergency supply issues, including interconnections between regional suppliers;

3) defining cost-effective procedures for dealing with aging infrastructure;

4) developing evaluation procedures for alternatives, and;

5) identifying preferred alternatives and other options that meet a variety of requirements in the areas of regional growth, environmental concerns, regulatory requirements and political realities.

To begin the study process, the PWB reviewed its "Strategic Direction and Mission" statement. This policy statement outlines a range of potential PWB roles in the region. These include:

1) being the regional water provider;

2) being the provider for Multnomah County, and others as water is available;

3) serving primarily Portland and providing water to others as available, and;

4) serving the historic service base, including its growth needs.

These roles create very different opportunities and requirements for the agency. Implicit in the PWB's IMP process was the objective of determining which of these goals is the most appropriate and which best serves the citizens of the city and its outlying areas.

3 CHALLENGES AND UNCERTAINTIES

The Portland Water Bureau has built a long-standing tradition of providing high quality reliable water to its customers for over 100 years. While this mission statement is not expected to change, the PWB will inevitably face challenges and uncertainties about the future. Uncertainties arise from five principal areas:

1) federal standards;

2) wholesale customers;

3) demand forecasting;

4) future supply, and;

5) climate variability.

Uncertainties surrounding federal standards may impact both water quality and quantity. Spawning and rearing habitat for endangered and threatened fish species in the lower Bull Run will require that an adequate volume of water is available during spring and summer months for these species. Since this time frame typically coincides with peak season water use, providing sufficient water for municipal, industrial, and fish demands becomes a challenge. There is uncertainty concerning the volume of water that will be required for spawning and rearing habitat. Currently PWB planners and limnologists are negotiating with the federal government in order to address this issue.

The current and long-term policy holds that the Bull Run will remain the primary water supply for Portland customers and the fish population native to the Bull Run. A number of policy-level uncertainties may dictate the future operation and ownership of the watershed, a prime example of these being the expiration in 2004 of the vast majority of wholesaler contracts. For example, westside customers may choose not to renew contracts with Portland and, instead, pursue another source such as the Willamette River. Eastside wholesale customers may chose to pipe Clackamas River water north instead of buying water from Portland. Alternatively, wholesale customers may assume a larger role in the ownership of the Bull Run. "Regionalization" is an option that has been investigated at a broad level, but uncertainties still exist.

Finally, uncertainties may arise from climate variability. The increase of carbon dioxide in the earth's atmosphere may have a profound impact on the future climate, namely temperature and precipitation. A growing number of water utilities have begun taking steps to address the impact of climate variability on future water supply systems. The PWB commissioned a study conducted by the University of Washington Department of Civil Engineering and the Climate Impacts Group that showed that the Bull Run Watershed may experience average warming trends of 1.5 degrees centigrade for the 2020 decade and 2 degrees centigrade for the 2040 decade. In addition, increased winter precipitation with less snowfall and more rain, and a decrease in late spring and summer precipitation may occur. Although uncertain, the effect of climate variability on hydrology and demand will increase water supply requirements by 2.8 BG on average, and as much as 5.4 BG.

Until they are resolved, these uncertainties prevent the finalization of a fixed long-term plan. Rather, a dual approach is being adopted that on the one hand deals with immediate, shorter-term issues unaffected by these uncertainties, and on the other hand deals systematically with the long-term issues over which the PWB has less control. The key objective of this parallel strategy is to maintain flexibility by implementing short-term projects in a manner that does not foreclose future options to meet long-term service needs. The examination of long-term options in order to determine their viability and engaging the City Council in discussion as regulatory and service area issues are being resolved are two components of this approach.

4 GROUNDWATER POLICY ISSUES AND CONJUNCTIVE USE CHALLENGES

The PWB has long emphasized protection of its water sources as its primary public health protection method. The Bull Run watershed protection program may be the most stringent in the U.S. In 1987, the PWB also developed one of the first comprehensive groundwater protection plans in the country.

Portland's groundwater system has served in two critical roles since the mid-1980s: 1) to augment Bull Run supply during the peak season, and 2) to replace the Bull Run when storm and other events make it impossible to serve Bull Run water. The future role of groundwater has been examined in some detail over the past two years as part of the IMP process and during ongoing communications with the public and Portland city officials. The current and expected future policy (at least for the next five to ten years) is that the Columbia South Shore Wellfield is Portland's secondary and backup source of water, and that Portland will use the wellfield to the extent needed to meet water demands that cannot be met by the Bull Run supply.

While the wellfield has been operated numerous times, there will probably always be public concerns about the quality of wellfield water relative to water from Bull Run. Interestingly, the debate appears to center around peak season use (when customers drink blended water), and not emergency use when customers drink 90 to 100% wellfield water. In any event, groundwater use during peak seasons may only be eliminated with a major expansion of Bull Run (construction of a third dam). It will probably be five years before it is known whether or not such construction could be permitted or built. As an alternative option to improve system reliability, PWB is currently exploring and examining Aquifer Storage and Recovery (ASR) conjunctive management.

The PWB's policy emphasis on protection allows it to use the least amount of treatment possible while still meeting federal and state regulations for both supplies. Both the Bull Run supply and the wellfield are treated only by chlorine disinfection of microbial contaminants. Despite the fact that the two sources require the same level of treatment, public perception of source water quality is quite different. The PWB has identified the deficiencies or needs of the wellfield as part of its capital improvement planning process. These are categorized as follows: water quality, long-term and short-term capacity and sustainability, operations & maintenance, vulnerability, groundwater pumps station, and institutional/management needs.

One of the primary challenges in managing the wellfield is the fact that the regulatory agencies overseeing cleanup of the contamination sites threatening wells will likely require cleanup only to the established criteria (the Maximum Contaminant Levels, MCLs), not concentrations that are below laboratory detection limits. Therefore, if Portland desires cleanup to non-detect, the city would probably have to provide treatment to remove Volatile Organic Compounds (VOC) remaining in the subsurface following cleanup activities. To date, the city has pursued a policy of aggressive investigation, cleanup and prevention of contamination as opposed to the wellhead treatment methods (such as air stripping) used by other water agencies. It remains to be seen whether or not this aggressive cleanup and prevention policy will sufficiently ensure unrestricted use of the wells in the future. Aquifer Storage and Recovery (ASR), if implemented, would potentially augment the prevention policy by replacing native groundwater (contaminated or not) with Bull Run water and also promoting an upward vertical gradient that would prevent pollutants from entering the critical deep aquifer system.

Regardless of the ultimate policy adopted with regard to peak season use, the wellfield will be essential for fulfilling winter demand during turbidity events for days or weeks at a time. This role could potentially change in the future as well, if Portland builds a water treatment plant that can handle the turbidity levels experienced in Bull Run during storms (possibly, up to 20 NTU or more).

Thus, the proposed policy asserts that the PWB will expand its existing wellfield to the extent possible, and as part of this expansion will develop an ASR system that would help minimize the quality differences between wellfield water and Bull Run water. This will assist in the fulfillment of other objectives such as increasing the overall reliability of the wellfield, protecting the wells from shallow groundwater contamination, and providing a means to maintain cool temperatures in the water distribution system during the summer. A proposed second wellfield in the Bull Run would support the existing wellfield and enable the Bull Run conduit system to remain operational during high turbidity periods.

5 DECISION SUPPORT SYSTEM (DSS)

In order to plan for the multitude of uncertainties that exist, the PWB has conducted a number of studies. Among these studies was the development of the Storage & Transmission Model (STM). The goal of this computer model was to allow PWB engineers and planners to simulate water supply and demand, as well as the water system's major transmission linkages, terminal storage, and supplies. By modeling the future water supplies and demands, PWB staff could assess how various assumptions about the water system actually perform during a 50-year period.

The STM model was developed by a team of researchers from the University of Washington, water resource engineers from CH2M Hill, and PWB staff. It was created using an iterative process requiring three phases of construction and critique. A number of fundamental issues concerning the modeling environment, appropriate time step, definition of the appropriate level of detail, and the user interface had to be resolved prior to actual model construction. As in most large water supply agencies, various perspectives existed concerning how a model might be best implemented. Throughout the model construction process, the model developers continued to recognize who would use the model and how it would be used in practice.

One approach that was used to ensure that the construction process would result in a successful tool was to identify essential questions that had to be answered by the PWB through the IMP process. Among these questions were:

1. What is the safe yield of the current Bull Run River water supply?
2. How much does the safe yield increase if Dam 3 is constructed?
3. How much does the safe yield decrease with less reliance on groundwater?
4. How much does the safe yield increase if the available storage is increased in Dam 2 by either increasing the operating height of the dam or providing increased treatment of the water?
5. Does the transmission system limit the PWB's ability to provide reliable service?
6. Should in-town storage be increased?
7. In what future years is increased supply required and where?

Model development was guided by determining how best these questions could be answered and how best the results of the model could be communicated to PWB management staff. An early, key question that required resolution was the choice of an appropriate modeling environment. The STELLA environment is growing in popularity because of its ability to create very large and powerful models using graphical objects rather than traditional line-based code. Selection of an appropriate time step was also resolved early in the process.

Defining the appropriate level of modeling detail was, perhaps, the most critical decision made by the modelers. Modelers commonly employ "Ockham's razor", a principle described by the fourteenth century philosopher William of Ockham, which states that "entities should not be multiplied unnecessarily" ("Pluralitas non est ponenda sine neccesitate"). This is often interpreted as meaning that the best explanation is the one that uses the fewest variables to answer a question correctly. This helps ensure that the model is appropriately simple, without sacrificing the model's accuracy. In the development of larger scale models, there is a constant and natural tension between making the model more detailed for the sake of completeness, versus adding only those elements that actually impact the model's final answer. As noted previously, the final model had approximately 1,200 variables for each daily time step. Although this appears to be extensive, it should be noted that the model does simulate a relatively complex supply and transmission system. The model was developed in fifty conceptual building blocks, and this approach helped provide users with an organization structure that provided an increased degree of clarity.

User interface design also presented a challenge. A successful model can be characterized by the extent of its use in facilitating and supporting decision making. Such usability could further be enhanced if the end user or the decision-maker can easily interact with the model developers. This interaction requires the understanding of the process involved in designing and developing the model. It also was recognized that the model was not an independent entity, but rather part of a broader planning process. As the planning process evolved, so did interface requirements of the model. To address these issues the model was demonstrated to PWB staff at regular intervals in order to receive their comments and critiques. Specific screens were designed with the staff to ensure that navigation through the model interface was intuitive and simple.

6 DEMAND FORECASTING

In 1997 PWB staff developed an econometric model to estimate daily demand. The model uses total daily production that is served to the retail and wholesale customers of PWB as dependent variable. Furthermore, daily precipitation, maximum daily temperature, seasonal variables, and population are part of the explanatory variables of the model. Also, a series of indicator and trend variables depict effects of conservation and long-term trends. Reliable daily production data dates back to 1960 and the weather data for the Portland metropolitan area dates back to 1940. The model is used for short and long-term forecasting and structural analysis of the aggregate demand in the Bull Run service area.

The functional form of the demand model is log-log format, which allows disaggregation of the effects of specific causative variables. The model is used to estimate weather-normalized demand along with more than sixty years of historical weather effects on demand. The weather effects are used to simulate demand for a specific population under different historical weather scenarios.

The STM study considered the entire Bull Run service area, which included 26 demand nodes. Some of these nodes were supplied by local sources in addition to PWB. Each node in STM required a separate weather-normalized demand forecast along with historical weather effects. Another demand model was developed based on production data available from TVWD. The model had similar functional form and included mainly similar independent variables. The two models were used for forecasting demand for nodes with similar water demand characteristics. Distribution of demand to different nodes provided the opportunity in STM to check for transmission bottlenecks under different demand and weather conditions.

Both demand models included population as a major deriver for long-term demand. Historical and forecast population figures were provided by Metro, a local government agency, in charge of land use and urban growth boundary in Portland metropolitan area. Metro provided annual population forecast for each STM node, which extended to year 2050. Population forecasts were used to distribute demand to each STM node.

STM Combines demand forecast for a specific year under historical weather conditions with historical stream flows to provide a measure for uncertainty in meeting demand. Different supply, conservation, and policy scenarios can be added to the simulation and the effect of each on uncertainty to meet the demand can be studied. In this regard, STM can be used as a powerful tool for short and long-term decision-making process.

7 DEMAND SIDE MANAGEMENT (DSM)

The historical retail and wholesale demand figures for the PWB show that since 1960 per capita demand has gone through three phases. The data show an increase in per capita demand in the 1960's and early 1970's, which could be as a result of cheap abundant water, big lot sizes, and inefficient water fixtures. From the mid 1970's to the late 1980's the per capita demand remained flat. This was followed by a dramatic decrease in per capita demand that can be attributed to several factors. First, in 1992, congress passed laws that required the use of efficient water fixtures in new constructions. Second, a drastic change in land use occurred, which resulted in smaller residential lot sizes and the development of more multifamily units. Third, conservation programs were adopted by various water providers in the region. These proactive programs included distribution of conservation kits, rebate programs, water conservation education programs, and increasing block rate structures.

An indicator variable included in the demand model depicts the effect of 1992 building code changes on demand. The model measures 5%-7% drop in demand that can be attributed to the code changes. An additional 10%-12% drop in demand can also be attributed to the various proactive regional conservation programs.

Demand forecasts provided for the STM include these drops in demand. Furthermore, a set of conservation targets based on a different study is incorporated in the STM to represent DSM as an alternative source of supply. Simulation of various demand and supply scenarios show that although DSM does not completely eliminate the need for new sources of supply, it certainly postpones implementation of large supply increments. The cost effectiveness of DSM can be measured by comparing the cost of its implementation with the time value of money resulting from the postponement of large supply increments like Dam 3.

Another important issue related to DSM is that the cost effectiveness of conservation programs disappears as soon as a large supply increment is added, since these usually provide beyond the immediate needs of the region. As a result, following the addition of a supply increment there is a period of abundance that compromises the relevance of conservation. Furthermore, since the useful life of these facilities goes much beyond their financial life, the marginal production costs plummet and render most conservation programs cost ineffective.

The need for additional water supplies relies heavily on the future M&I and fish demands of the region. Even after these issues have been sufficiently defined, uncertainty will exist in finding a source or sources of supply that will reliably meet forecasted demands

8 SUCCESS OF THE STM AS A DECISION SUPPORT TOOL

As noted earlier, it is difficult to determine the success of a decision support tool that is being used in infrastructure planning. One typically does not have the luxury of performing a blind test in which top level managers in a utility are asked to rank project alternatives with and without the information generated by the computer support system. In addition, the value of a decision support system like the STM accrues not only during the analysis stage but also throughout the planning process. In the development of the model, PWB staff often were challenged to think carefully about their system, how it could best be characterized, and if all members of the staff agreed upon key operations and policy issues. The process of creating a model, of translating the concepts and ideas associated with a system into a codified set of evaluation procedures forces a systematic evaluation of assumptions requiring participants to think about individual components of their system, as well as the system as a whole, in new ways. This can often have positive results.

The STM combines demand forecast for a specific year under historical weather conditions with historical stream flows to provide a measure of uncertainty in meeting demand. Different supply, conservation, and policy scenarios can be added to the simulation and the effect of each on uncertainty. In this regard, the STM is a powerful tool for short and long-term decision-making processes.

9 CONCLUSIONS

Infrastructure planning presents particular opportunities for water supply utilities. For the Portland Water Bureau, it provided the agency an opportunity to evaluate how these planning efforts could be integrated with an existing regional water supply. It also allowed the PWB the opportunity to develop tools that enhance its ability to plan.

In the Infrastructure Master Plan process, a number of issues were identified that helped guide the creation of the STM. Stated simply, the model had to support the PWB staff in determining if there were advantages in expanding PWB's service area and how conservation and other alternatives would be used to meet their primary goals. The goals of producing safe, inexpensive, and reliable water remain unchanged. This paper has suggested that decision support tools, such as the STM, can play a significant role in helping throughout the planning and analysis process.

The DSS allows the PWB to simulate existing and future water demands, major transmission lines, and reservoirs. With the STM the PWB can evaluate system performance for specified surface water operating rules, use of groundwater, conservation options, flow requirements for fish, and system expansion options.

The uncertainties facing the PWB do not permit the definition of a single plan. Rather, the PWB needs to maintain flexibility in the water system and in its approach to water supply planning. The IMP analyzed several “what-if” scenarios, but it is likely that new options will arise in the next few years. Thus, these scenarios are periodically reevaluated using the analytical tools developed as well as policies and regulatory requirements. The result of this reevaluation will inform the PWB’s financial plan and the Capital Improvement Program (CIP). Over the next two years the PWB will conduct a similar master-planning project for its extensive distribution system.

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