West Edmonton Sanitary Sewer Tunnel W12

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1 Introduction

The North Saskatchewan River flows southwest to northeast through a 22-km valley in the City of Edmonton—the largest stretch of urban parkland in North America. It supplies drinking water for Edmonton and dozens of downstream communities. The City of Edmonton, like most pre-1940 municipalities, is serviced in part by combined sewers. These sewers occasionally overflow into the North Saskatchewan River in heavy rains. The Rat Creek outfall was responsible for 60–80% of the City of Edmonton's combined sewer overflow volume—3.2-billion litres per year—affecting water quality in the North Saskatchewan River and raising safety concerns in Edmonton and beyond.

The $44-million West Edmonton Sanitary Sewer project W12 syphon across the North Saskatchewan River connects the Rat Creek combined trunk to the South Highlands Interceptor and then to the Gold Bar Wastewater Treatment Plant (Figure 1). This was expected to reduce the CSO discharges into the North Saskatchewan River by up to 80%, significantly improving water quality.

1.1 Challenges

The design and construction of W12 proved to be extremely challenging. Most of the project is situated at an extreme depth—75 meters below downtown Edmonton—within the footprint of abandoned coal mines. Five deep shafts and a 1.2-km tunnel would have to be constructed in ground laden with coal seams, water pockets, and voids, with methane gas under pressure detected in several locations. Access was also severely limited: the northern construction site was in Edmonton's downtown, and most of the tunnel alignment was under the Riverdale Golf Course and the river itself, running vertically between two coal seams.

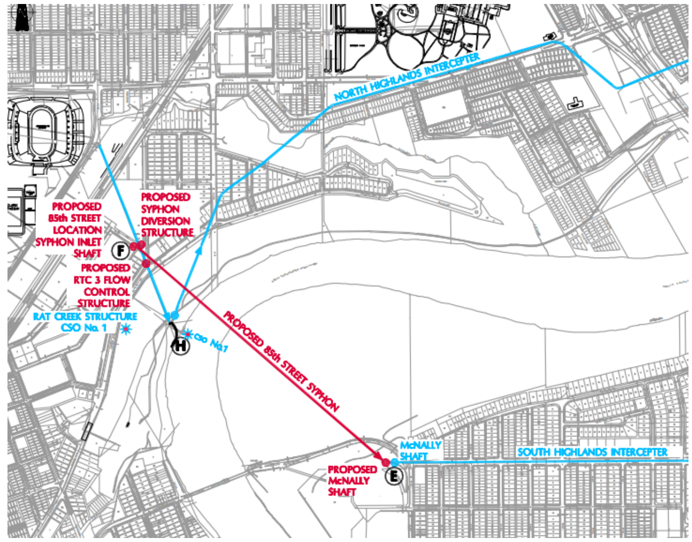


Figure 1. Project Layout

The deep shafts and tunnel length meant delays in removing soil and supplying construction materials, and shaft placement was limited. Construction of the real time control structure required tying into a live old, brick 3200-mm pipe. This pipe had high dry weather flows (3.7 m/s) and the potential for even higher velocities during sudden rainstorms—a major safety concern. Multiple rounds of modeling helped simplify the construction approach.

The tunnel had zero-exfiltration standards due to its environmentally-sensitive location in the river valley. The north end of the syphon was in a residential area, so special odour scrubbers were also required. To avoid flooding basements upstream or releasing unnecessary CSO into the river, the complex real time control structure (RTC) would need to function flawlessly, with rigorous gate control requirements. Additionally, several downstream projects were implemented to provide connection and functionality of the sewer system. Due to the uncertain ground conditions and other constraints, the City Drainage Design and Construction crews initially planned to work with a newly-acquired LOVAT Earth Pressure Balance tunnel boring machine, using bolted segmental liners—the best technology for the job, but one that was new to the City of Edmonton's crews. The deep shafts meant delays in removing soil and supplying construction materials, and shaft placement was limited.

The construction of the project was completed in 2012 and successfully began conveying flow to Gold Bar Wastewater Treatment Plant. CSO events were reduced 98% in the first year of operation, exceeding design expectations.

Project Challenges

Site Location

- 75 m below downtown Edmonton

- Geotechnical challenges: coal seams, water - pockets, sub-surface voids

- Methane gas

- Environmental challenges: access and laydown, construction disturbance

Integration

- Tying into existing system under live flow

- Downstream projects required to integrate into the existing system

Requirements

- Reduce CSO events 80%

- Zero-exfiltration standards

- Manage and control odour

- Complex RTC structure with rigorous gate control requirements

1.2 Project Team

When the unique challenges facing this project became clear, the City of Edmonton's Drainage Design and Construction Branch brought in Associated Engineering (AE) to design the tunnel and SMA Consulting (SMA) to optimize the project's construction delivery. AE was the lead design consultant, providing preliminary and detailed design services for the implementation of the W12 tunnel and additional projects linking it with the City's existing drainage network. AE's role in the project included construction cost estimating; design of control structures and tunnel connections; hydraulic modeling of the system and syphon; computational fluid dynamics analysis of the inlet, control structures, and drop shaft; odour control design; environmental impact mitigation; and public consultation.

Due to the complexity of the project, the project team implemented a collaborative design process using sophisticated decision support tools to take advantage of the City's knowledge of both its existing infrastructure and of the construction techniques they would be using. A series of workshops and special studies was led by SMA; AE contributed their expertise in risk and value engineering workshops and by assessing constructability options and risk. SMA undertook over a dozen studies in risk analysis and management, constructability reviews, and value engineering. Innovative techniques were marshaled for use during these studies—Failure Mode and Effect Analysis (FMEA), construction simulation, and 3D and 4D visualization—which supported a number of key decisions over the course of the project. Decisions were made in a workshop environment, and involved participants from Drainage Design and Construction, Drainage Operations, Associated Engineering, Drainage Planning, and several external experts. SMA was also instrumental in construction controls, preparing daily site visit reports, tracking the budget and schedule, and using forecasting techniques to predict future performance. Productivity analysis using the Method Productivity Delay Model technique was also performed to identify areas where improvements could be made.

2 Innovative Techniques

The W12 tunnel as it was constructed has three shafts: one at McNally, one at Dawson Park, and one at 85 St. (Figure 2). The tunnels were ultimately constructed in two drives. Rib-and-lagging was used as the primary liner, with HOBAS pipe as the secondary liner. The RTC structure contains two control gates and a diversion gate, and involved sinking another two shafts at 85 St. A temporary bypass was constructed first to divert flows and allow construction in dry conditions.

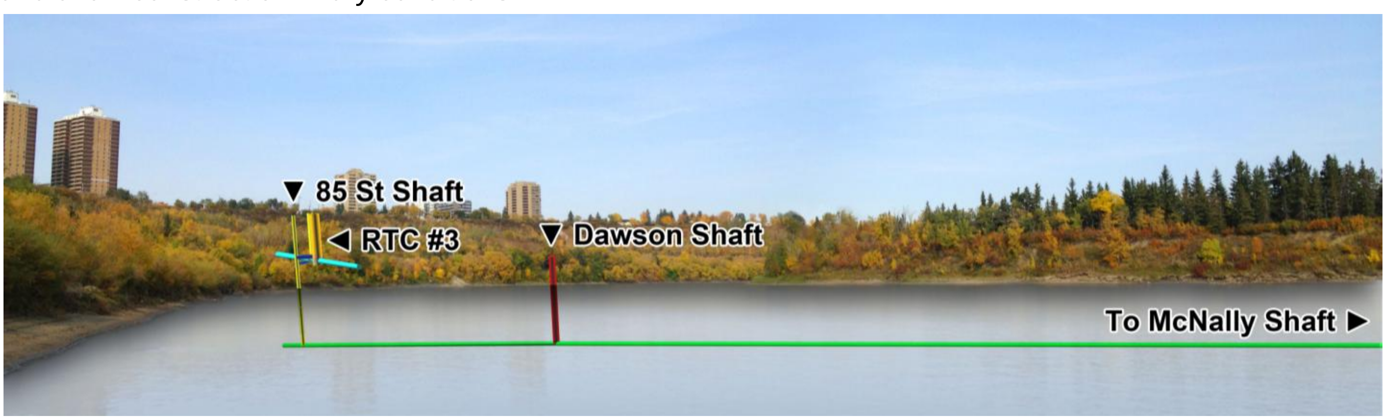


Figure 2. Project Overview

During the course of the project, Associated Engineering brought several advanced modeling techniques to bear on the design: computational fluid dynamics, particle modeling, and air flow and odour modeling, among others. SMA also employed multiple techniques to assist Drainage Design and Construction in making decisions. The keystone technique used in decision support was risk analysis, which was instrumental in informing all decisions and was integrated into many of the other techniques. The challenging nature of this project required that risks be mitigated as completely as possible, and a full risk management plan was developed to ensure the mitigations were implemented. In addition to risk analysis, three additional

Innovative Techniques

Computation Fluid Dynamics • Particle Modeling • Quantitative Risk Analysis • Constructability Reviews • Value Analysis • Construction Simulation • 3D and 4D Visualization • Failure Mode and Effect Analysis (FMEA) • Analytical Hierarchy Process advanced techniques were used: construction simulation, 3D and 4D visualization, and Failure Mode and Effect Analysis (FMEA). These were typically employed as part of risk analysis, value engineering, or constructability workshops.

2.1 Hydraulic and Particle Modeling

Associated Engineering used advanced hydraulic modeling techniques in designing the W12 project, including particle models, computation fluid dynamics (CFD) models (Figure 3), and a physical model of the tunnel itself. University of Alberta researchers were brought in to help develop and review the models. The real time control structure was especially challenging to model, and multiple rounds of modeling were required as constructability challenges and limitations were identified. The effects on the entire system also had to be investigated, and several critical downstream improvements and changes that would be necessary for W12's full operation were identified.

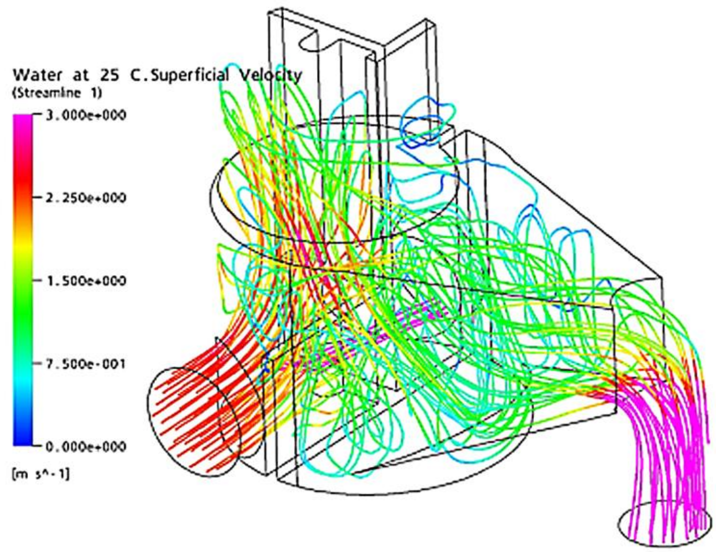


Figure 3. Hydraulic modeling results

A grit analysis was also performed, which considered particle size, settling velocity, scour velocity, rising velocity, gate opening speed, and flow volume. All were analyzed to optimize the operation and efficiency to minimize life cycle operations and maintenance costs. The analysis was used to show that the $7-million pump station in the original design could be eliminated as the scouring action of the high flow through the pipes would remove over 99% of the grit.

2.2 Construction Simulation

SMA's award-winning simulation modeling approach develops construction plans that are accurate and transparent, especially for tunneling projects. Those plans account for resource interactions, processes on site, external interferences with the project, and various constraints. Staging scenarios can be studied once the plans are in place. Site layout, site access, auto traffic, and pedestrian interference with construction processes can be analyzed and designed for (Figure 4). The results are realistic project plans that account for project constraints and interactions with the outside world. A significant merit of simulation models over traditional forecasting methods is the factor of randomness beyond that of distribution sampling. In simulation, it is possible to define dependencies between various entities such that their interactions, and therefore the process itself, in part, can be part of the simulation outcome.

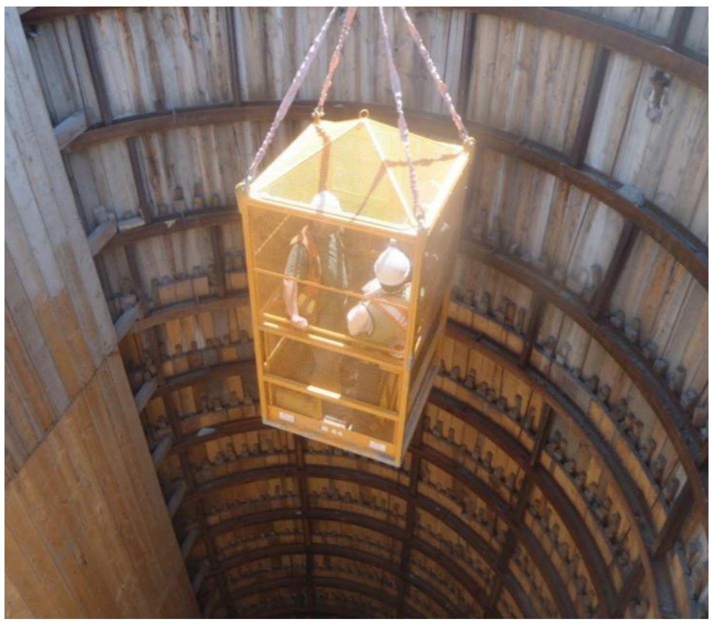


Figure 4. Descending the shaft

2.2.1 Tunneling Sequence: South, North, or Two Ways?

SMA developed three discrete event simulation scenarios to support the decision of which tunnel sequence to use. Tunneling from 85 St-McNally or vice versa would require hauling material from the bottom of the tunnel up to the top of the bank, which impacted productivity significantly in simulations.

After a risk and cost-benefit analysis of all three options, the preferred option was determined to be two-way tunneling. The option had the least amount of risk associated with it and would not require a specialty high-speed hoist or the completion of the 85th St shaft prior to commencement of tunneling. Finally, an analysis of expected costs and schedule indicated that two-way tunneling was less expensive and likely to have a shorter project duration.

2.2.2 Secondary Liner Analysis: Concrete, Precast, Steel, or Fiberglass

There were multiple reasonable choices for secondary liners to use in the tunnels: cast-in-place concrete, precast sections, steel pipes, or HOBAS pipe. To support the decision process, SMA developed discrete event simulation scenarios to explore the schedule implications of each choice. Through consultation with the project team and a review of relevant literature, various assumptions were made: shift length, tunnel length, average production, distance between pumping wells, duration of concrete pouring activities, duration for track installation, time for grouting, and so forth.

The simulation models were developed in Simphony, tested, and run. The simulation result showed that the total duration for cast-in-place liners was 220 days. If precast pipe sections were used, the duration was 204 days; steel pipes with lining were 184 days; and HOBAS pipes were 172 days.

A value analysis workshop was then conducted to discuss these choices, employing the Analytical Hierarchy Process (AHP) as the decision-making platform. The results of the AHP resulted in the selection of HOBAS pipes as the option with the best value, the most schedule-friendly, maintainable, efficient, and constructable.

2.3 3D and 4D Visualization

3D models of individual pieces of the structures to be built are constructed in CAD software to the exact specifications provided by the design/drafting team. As in the real structure, the model pieces can then be arranged into substructures, and those are subsequently assembled into structures of increasing complexity. We then employed additional modeling software to manage the model pieces, their arrangement, and their sequence in a construction context, giving the visualization a fourth dimension: time. Video replay of a construction sequence is an invaluable discussion tool.

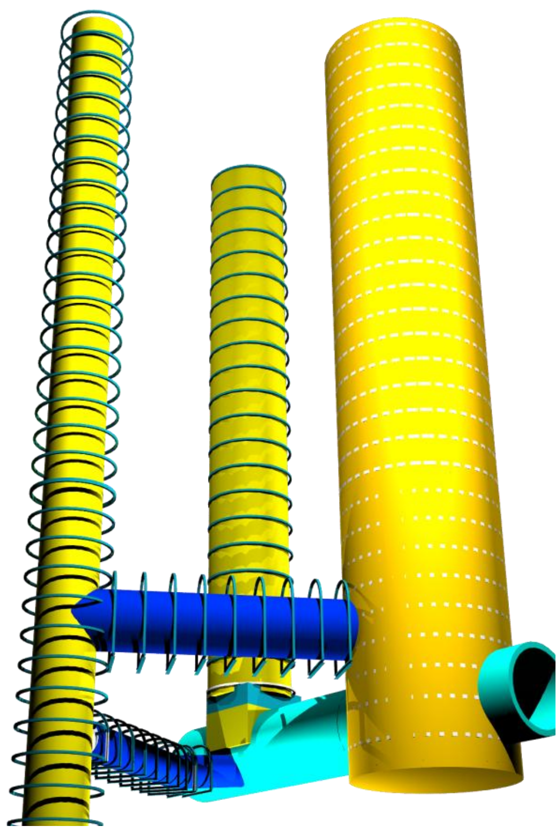
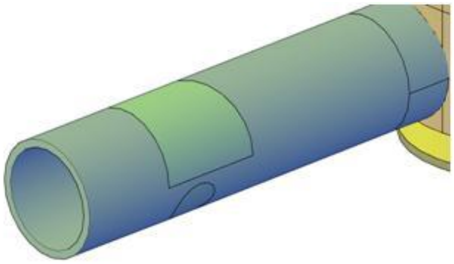


Figure 5. RTC Overview

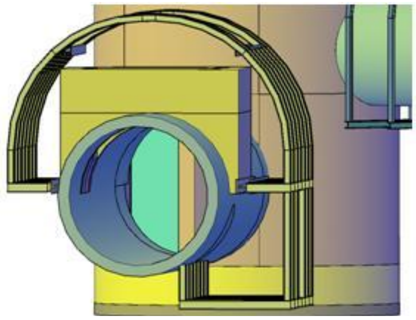
2.3.1 RTC Constructability: 5 Options

AE identified five options as being feasible construction options for the configuration of the three RTC shafts (Figure 5) that satisfied the required diversion and the intended hydraulic design. In order to select the best option, SMA facilitated a structured selection process based on value analysis, constructability reviews, and risk analysis. Value analysis was used to identify the options with a high value and present them for further analysis. Constructability reviews were conducted to understand the construction process and the construction challenges by the City of Edmonton’s crews. After that, risk analysis was undertaken to identify and evaluate the option's risk and integrate that risk value in the selection process. This value analysis led to the initial decision to proceed with a two-shaft option, on the alignment but with a bypass and a "bulkhead shaft."

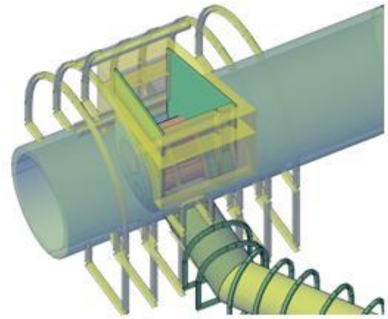
In order to provide a clearer understanding, SMA created a 3D visualization of the RTC structure and used that model to create a 4D visualization depicting the construction of the RTC structure as it was proposed. The animations generated were an invaluable visual aid, allowing decision-makers to see the process taking place without ambiguity. Figure 6 shows the sequence.



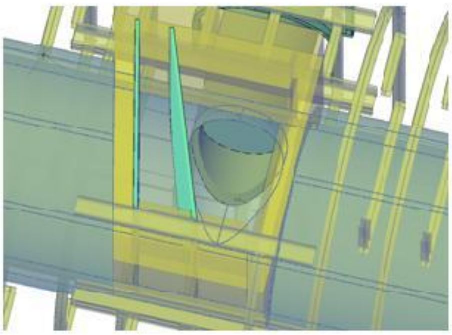
1. Remove panels and install plug in bypass pipe. Flow is now through RTC



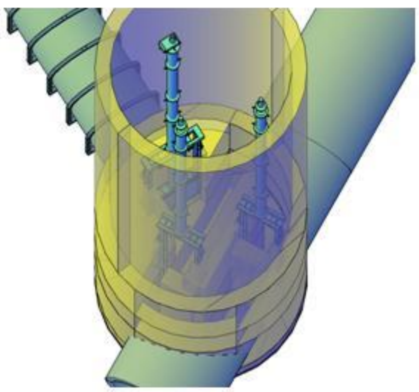
2. Install pipe inside existing pipe to carry flow and allow safe work in the pipe



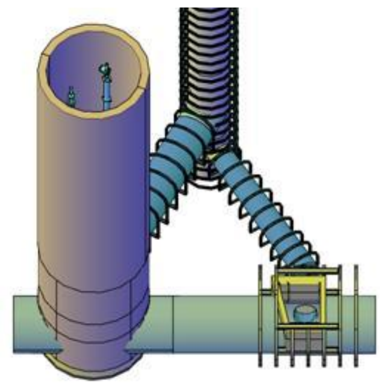
3. While flow is bypassing, build RTC



4. Install panels to redirect flow into bypass



5. Cut existing pipe



6. Build structure to hold panels

Figure 6. Overview of RTC construction

2.4 Failure Mode and Effects Analysis

Because the RTC gate operation was critical to the success of the project, a full failure analysis was performed. Failure Mode and Effects Analysis (FMEA) is a method that examines potential failures in products or processes. FMEA helps select remedial actions that reduce cumulative impacts of life-cycle consequences (risks) from a systems failure (fault).

Using FMEA and Event Trees, a study was undertaken to determine the failure modes and probabilities and effects of failure of the control and diversion gates in various events. The overall conclusion was that the shaft configuration presented in the workshop was determined to be acceptable to be implemented. Mitigation strategies were also identified for the failure modes. Detailed design of the RTC and diversion shafts proceeded on the basis of geometry presented in the workshop.

2.5 Risk Analysis

Representatives from AE and the City of Edmonton lent their expertise to the risk analysis workshops SMA facilitated. The "Structured Risk Analysis Process" used in these workshops was developed by SMA and refined over the past ten years. This process relies on a wide range of experts and stakeholders providing their expert opinions as they brainstorm together to identify, quantify, and mitigate risks. Quantification is carried out utilizing approximation tables for likelihood estimation, impact estimation, and severity interpretation. An overall risk allowance is developed for the project to assist cost estimation and budgeting.

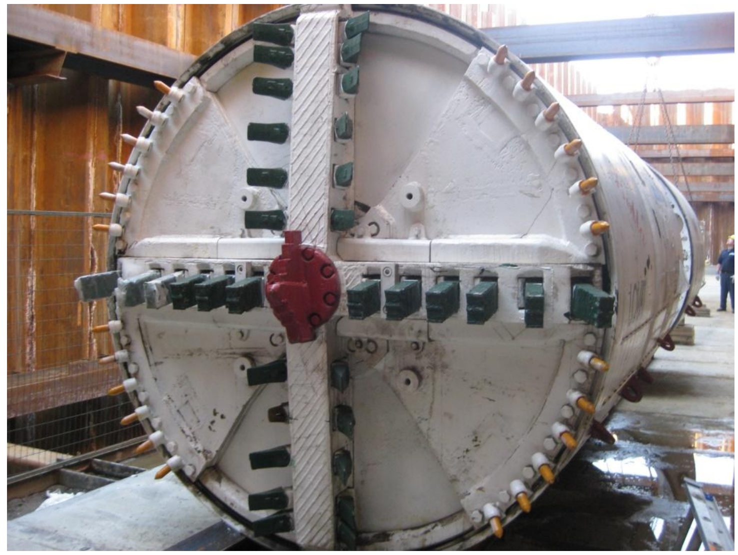


Figure 7. Tunnel boring machine

2.5.1 Choice of excavation method and liner type

One of the key decisions made in the course of the project was the type of excavation method that should be used. Risk analysis, construction simulation, and constructability reviews were conducted in 2005, 2006, and 2007 to investigate the merits of multiple types of excavation methods and liners.

The initial choice was to use bolted, segmented liners applied by an earth-pressure balance machine (Figure 7). A construction simulation performed to investigate the productivity levels achieved with cast-in-place liners forecast the project duration at almost double the duration using bolted segments. Two additional shafts would also be required.

The risk analysis established that the City's current TBMs required expensive, extensive refurbishment in order to handle the bolted segments, with some question as to the reliability of the TBMs even if the refurbishment were performed. The EPBM was chosen due to the expectation of encountering coal seams, voids, water, and other mixed materials during excavation. There was also the risk of failure of the City's current TBMs, which at the time were primarily past their half-life spans. Failure under the river or the golf course was identified as another severe risk factor.

2.5.2 Lot Purchase for Shaft Placement

In 2005, AE identified the opportunity involved in purchasing the corner lot at 85th Street and Jasper Avenue and using it for building the shafts and housing operational facilities. There were several advantages of moving the shafts from the proposed locations in the preliminary design to the proposed lot, including allowing free movement of traffic and pedestrians around the job site, no need to relocate utilities, and allowing odour control and gate control facilities to be housed above ground. The decision to purchase the lot was estimated to save the City approximately $300,000.

A meeting was held to discuss the potential elimination of the pump station. The expected pump station cost had grown to approximately $7 million. The pump station was included to facilitate solids/grit removal, odour control, and inspection. AE analysis determined that the first two issues could be dealt with through RTC functions available to the project. In addition, the expected solids accumulation per year was estimated at up to 1% of volume, requiring over 50 years to reach full capacity. Ultimately, the risk assessment established that a pump station was not required for this project since the costs were not justified and the functions could be achieved through RTC functions.

2.6 Project Controls

In addition to the advanced techniques used for decision support, SMA also used advanced techniques during the project construction to identify productivity issues and find solutions. A Project Execution Plan was developed and throughout construction, progress reports were generated daily to document, both quantitatively and qualitatively, the events, progress and challenges on site. Components of Earned Value Analysis were also employed to facilitate project control, namely, cost and schedule performance indices. The expected budget and duration for project completion were calculated and updated on a monthly basis.

When the progress tracking and earned value identified issues with the tunnel productivity, the Method Productivity Delay Model (MPDM) technique was used to quantify defective components and pinpoint the sources of delay during day-to-day operations for several months. This technique helps to focus on solving specific issues, improving the overall performance. Production is tracked for every shift, and interruptions are recorded via a data sheet and allocated by percentage to certain causes, such as external (e.g., weather), electrical, crane, and so forth. The amount of delay allocated to each cause can then be calculated and the key causes quickly become clear.

3 Environmental Benefits

The City of Edmonton's combined sewers, many of which were built before the 1940s, occasionally overflow into the North Saskatchewan River in heavy rains. Until 2011, the combined sewer overflow (CSO) discharging from the Rat Creek outfall was responsible for 60–80% of the City of Edmonton's combined sewer overflow volume. The effects of this overflow affected the quality of the water and fish and aquatic habitat in the North Saskatchewan River, and increased safety concerns in Edmonton and in communities downstream.

Environmental Benefits

98% reduction in CSO events at Rat Creek

Improved water quality

Improved fish and aquatic habitat

Reduction in odour and erosion at Rat Creek

Careful planning to avoid damage to River Valley during construction

The primary design goal of the W12 syphon was to reduce the CSO discharges into the North Saskatchewan River by 80%, significantly improving water quality. Reduction in discharges from 49 per year and 3.2 billion litres (1998 baseline) to less than 10 per year would be satisfactory. However, the actual performance of W12 in its first year of operations was a 98% reduction in CSO events. Only one CSO event occurred in the first year, and that was during a record-setting 1 in 200 year storm which caused flooding all over the city.

The construction of W12 was also planned to have minimal impact on the sensitive River Valley. The laydown site was placed within a park, which was then extensively re-landscaped after the completion of the project. Only existing access roads were used, and trucks and cranes were barged across the river where necessary (Figure 8).

Figure 8. Cranes for W12 project: equipment was barged across to avoid damaging the River Valley

4 Social and Economic Benefits

In addition to the environmental concerns, one of the main goals of this project was to increase drainage servicing to northwest Edmonton's new neighbourhoods. As a result of the success of this project, those areas now have the basic infrastructure to allow for growth and economic development.

Economic and Social Benefits

Cleaner water for Edmonton and downstream communities

Two newly created/renovated parks

Flood protection

Odour control

Cost-saving design decisions

4.1 Satisfied Residents

Extensive public consultation was undertaken prior to the construction of W12, including meetings with small business owners and local residents. A survey of residents indicated that 100% were satisfied with the displays and answers.

4.2 Odour Mitigation

Because the operations facility is located in a high-density residential area, odour was extensively discussed, modeled, and investigated. Special odour-scrubbing filters were installed to mitigate the potential for odour on the north side of the syphon.

4.3 Highest Value Design Options

The sophisticated decision-making techniques applied throughout the design and construction phases of the W12 project have resulted in the selection of the highest-value design options. A value analysis of the options for the secondary liner, lot purchase, lift station elimination, and construction techniques would result in savings of several million dollars (20% of the project cost).

4.4 New Parks

One large park was re-landscaped and updated to reflect current best practices on park design. In addition, landscaping and several benches have been designed for the operational facility area and will be installed when the weather allows.

5 Conclusion

The City of Edmonton's two primary goals with this project were to (1) reduce the CSO discharges at the Rat Creek outfall by 80% and (2) provide sanitary and stormwater servicing for new neighbourhoods in northwest Edmonton, in order to facilitate growth and economic development.

Meeting Client's Needs

In 1998, the Rat Creek outfall experienced **49** overflow events. In W12's first year of operations, only **one** CSO event occurred at the Rat Creek location: a 98% reduction, exceeding design expectations.

SMA and Associated Engineering worked together to find effective and cost-efficient solutions for this complex project. Using advanced design tools and decision-making techniques, these consulting firms supported the City of Edmonton in determining project sequencing, analyzing and selecting cost-effective options, and navigating the complex physical requirements of the tunneling process.

In a project as complex and fraught with risk as W12, it is important to make decisions in a framework that engages stakeholders and allows for the incorporation of information from multiple sources. The use of these tools was instrumental in many of the key decisions made during the project, including the design, the style and sequence of construction, and the ultimate operation.

It is also the case that good decisions cannot be made in an informational vacuum. Daily documentation of project progress and the use of project controls techniques such as EVA and MPDM provided information to project managers and was key in change management.

The work done by SMA and Associated Engineering has resulted in a successful project for the City of Edmonton. The number of CSO events at Rat Creek was significantly reduced. Additionally, flow is being conveyed from Edmonton’s fledgling northwest neighbourhoods, thereby allowing Edmonton to expand and develop economically.

The project was completed with no safety issues. W12 is currently operating as planned and the CSO volume entering the North Saskatchewan River has been reduced significantly, improving water quality for municipalities downstream. As more of the West Edmonton Sanitary Sewer is brought on line, W12 will continue to facilitate the reduction in combined sewers in Edmonton. Good decisions mean successful projects, and successful projects mean better service for the taxpayers of Edmonton.

West Edmonton Sanitary Sewer Tunnel W12

☑ Challenging project from design and construction perspective

☑ Applied wide range of analysis and modeling techniques

☑ Minimized project cost

☑ Exceeded design expectations

☑ Improved environment and minimized impact during project

☑ Cleaner water and better flow for neighbourhoods in Edmonton and downstream

☑ Benefited the citizens of Edmonton