challenge NETWORK

ISSUE NO. 77 FEBRUARY 2014 A technical journal by Parsons Brinckerhoff employees and colleagues http://www.pbworld.com/news/publications.aspx

PARSONS BRINCKERHOFF

WATER

Managing Our Most Precious Resource

Water: Managing Our Most Precious Resource

Introduction: Regional Perspectives on the State of Water

In the year 2013, the global population passed the seven billion mark and, as a result, it's clear that the burden placed on our finite water resources is only going to increase. The water industry has to contend with aging systems in addition to a changing environment. This, together with the global economic downturn since 2008, has created a challenging few years for the water industry as a whole.

Water is one of those finite resources we can't do without. Water scarcity and extreme weather—not enough water here, too much there—bring water management to the forefront[1]. Our industry, including the professionals within Parsons Brinckerhoff, will need to continue to collaborate and innovate ways to manage and use this precious resource sustainably and for the benefit of the world's population.

As an introduction to the global needs of water resources and water infrastructure, we have invited some leading Parsons Brinckerhoff water professionals to describe the challenges and major issues that face their regions. This introduction provides a broad view of the types of water projects that Parsons Brinckerhoff is now performing and likely to be involved with in the future. The regional perspectives describe future demands for different types of water infrastructure, factors driving the industry, strategic directions, and areas needing innovation in engineering or delivery.

This issue of Network presents a significant number of projects in which Parsons Brinckerhoff has been involved in this collaborative and innovative environment. *(As an example, see the article by Mary Fickert Thomas and David MacIntyre on developing technical tools and processes for collaboration among regulatory agencies for regional water policy.)* The projects demonstrate a wide range of practice areas and capabilities related to the management of water and water infrastructure. Therefore, in order to help you find the most relevant ideas and information, the 24 articles have been organized into sections on:

- **Flood Control and Hydraulic Structures**
- **Water Power**
- **Water Resource Planning**
- **Stormwater**
- **Water Quality and Conservation**
- **Drinking Water Treatment Technologies**
- **Infrastructure Maintenance and Repair**
- **Wastewater**

Each section consists of several articles that demonstrate a range of capabilities in that practice area. For example, the section on Stormwater includes articles on a variety of types of projects:

- The stormwater detention element of a highway design-build project *(by Colin Haggerty and Robert Welch)*;
- The use of best management practices for stormwater retrofitting of communities *(by Kelly Lennon et al.)*;
- A methodology for inspection and condition assessment of stormwater channels *(by James Chiang et al.)*; and
- The implementation of green stormwater infrastructure for roadway drainage *(by Tye Simpson et al.)*.

The following overview should provide a better framework and context for scanning the wide range of articles on water projects that are representative of Parsons Brinckerhoff's capabilities.

The State of Water in the UK and Europe

by **Jonathan Ralph**, Bristol, UK, +44 1179 339384, RalphJ@pbworld.com

Within the UK, the Parsons Brinckerhoff team has worked on some high profile and exciting projects, including the Severn Tidal Power Study, which looks at the potential to use tidal energy to generate power in a location with one of the world's largest tidal ranges (14m/30ft). Engineers considered a range of aspects including marine engineering, navigation, climate change, flooding, and

[1]Water Online, "Water Projects That Will Transform North America", Kevin Westerling, October 1, 2013

river modelling. *(See the article by Peter Kydd, "Tidal Power – An Emerging and Predictable Source of Energy".)*

There have also been changes within other water sectors. Flooding and climate extremes continue to impact our environment, as recently demonstrated with the significant rainfall experienced in January 2014 in the UK and the effect on local communities in low-lying areas such as the Somerset Levels. Following significant flooding in 2007, the UK has made great strides in developing a flood modelling system and in understanding flood risk to ensure that appropriate development occurs at the right location. Significant funds are also being invested in river, coastal, and infrastructure defences in recognition that the social and infrastructure costs of flooding are very large. *(See the articles by Charles Bennett on responding to groundwater flooding; by Paul Carter and Alan Knott on a flood forecasting modelling system in the UK; and by John Boulé and Jennifer Itri on Parsons Brinckerhoff's broad approach to flood mitigation and resiliency following a number of major storm disasters in the US.)*

Within the more traditional water and wastewater sectors of the industry, the need to provide cost effective long-term solutions has led the UK's regulatory bodies to change how the market will be measured over the next regulatory period, 2015 to 2020. This regulatory cycle, known in the UK as AMP6 (Asset Management Programme 6), has placed more emphasis on the overall cost of a project, now referred to as TOTEX (total expenditure). The industry also recognises that 'outcomes', rather than 'outputs', need to be considered. This attracts innovation, which is also recognized as an important part of the water sectors' development. As an example, instead of constructing a treatment plant to improve a river's quality, consideration would be given to improving the local farming methods to prevent discharges into the river and reduce the river's load.

Significant savings have been seen by a focus on the carbon footprint of a construction site, and moving from in-situ concrete construction to precast concrete, or even the use of GRP (glass-reinforced plastic) where appropriate. Parsons Brinckerhoff has also been developing water footprint tools to measure water usage in the industry so that we can continue to strive for more effective and sustainable use of our water resources in both manufacturing and construction.

Parsons Brinckerhoff will continue to develop solutions to the water challenge by drawing on its global community of professionals ensuring that our clients get the knowledge and experience of many with the consistency and low risk of dealing with one overarching entity.

The State of Water in Australia

by **Tom Mosquera,** Sydney, AUS, +61 2 9272 5251, MosqueraT@pbworld.com

The last ten years in Australia have seen the largest water infrastructure growth in a generation as most major cities and large mining areas experienced an unprecedented demand for secure water supplies. This was coupled with an extended drought over much of Australia that highlighted a lack of resilience in urban water supply systems. Many urban water utilities diversified supply and sought to control demand to be less prone to the impacts of drought. This led to the construction of a number of major desalination plants in the major cities, other water harvesting techniques, and control of demand by incentivisation.

The drought brought water to the height of the political agenda with one of Australia's largest rivers coming very close to irreversible environmental damage. With the breaking of the drought, it remains to be seen whether more effective approaches to managing such iconic areas will be fully implemented. These include such strategies as salinity management, technological innovation in irrigation, water entitlements and trading. *(See articles by Susan Kizito, Mei Yau, Gary Thorne and Joel Segal which describe the provision of water infrastructure services and technologies to remote communities with limited water resources).*

Urban water utilities were largely effective in supply management and there is no longer a crisis in supply or conveyance. Utilities have been effective in managing both water and wastewater networks with new construction and augmentation. The majority of this work was delivered through alliances and an approach of "getting the job done as effectively as possible". *(See Matt Brown's article which describes part of Parsons Brinckerhoff's role for the North South Interconnection project in Adelaide.)*

In Australia, each state has an independent regulator and, with the immediate and urgent impacts of the drought now addressed, the focus has changed to the high cost (that has been rising much higher than background inflation) of water. For at least the next five years, and possibly the next ten, there will be a significant pressure on water utilities to demonstrate improved value for money and efficiency in asset utilisation. Utilities are changing their procurement models and recontracting projects under asset management programmes, similar to the approach adopted in the United Kingdom following regulation in its water industry. *(See the article by Anthony Domanti which explains how a planning-led alliance can unlock value for utilities.)*

The key aspect of these models is to provide an increased competition framework with an integrated supply chain of designers and constructors. This will mean that consultants will be required to take on 'outcome risk', and only those willing to do so will survive in the long-term.

The nature of the work will be more capital maintenance driven—augmenting and extending asset performance without significant new construction. Leading this change will be a need for water utilities to significantly increase their asset knowledge.

Parsons Brinckerhoff is approaching this market with three key strategies:

- Provide services that enable clients to understand and strategically plan their asset renewals program;
- Integrate with the new infrastructure delivery models and be prepared to take on and manage delivery risk; and
- Continue to provide water utility clients with professional services that are adapted to the new procurement frameworks.

One of the most exciting aspects of the significant and uncertain change that the water market in Australia is undergoing is that, while struggling to react to these changes, the market is ripe for innovative approaches and technologies. Balfour Beatty Gas and Water in the UK has been working in the area of Network Intelligent Solutions and has developed technologies that enable significantly increased asset inspection without invasive techniques. This knowledge will allow our clients to make better informed investment decisions. Parsons Brinckerhoff and Balfour Beatty are working in partnership to bring this to market while continuing to investigate other innovative technologies. *(See the Mike Brockhurst and Kathryn Vowles article, "In-Situ Pipe Lining - Innovation and Market Acceptance".)*

For the next five years, the state of water in Australia looks to be uncertain, exciting, and will be very dependent on whether another extended drought brings it to the fore of the political landscape, demanding ever more effective supply management.

The State of Water in Middle East and North Africa (MENA)

by **Paul R Jones,** Doha, Qatar, +974 4435 1612, jonespa@pbworld.com

The Middle East and North Africa (MENA) region is one of the driest regions in the world and Kuwait in particular claims to be the hottest inhabited country in the world. It is against this background, and in contrast to this perception of such a dry region, that we find opportunities and challenges in all sectors of the water market - including water supply and treatment, foul and surface water sewerage, and flood defense.

Water supply and treatment are high on the list as there is an ongoing need to develop existing supply networks to cope with increasing populations and to improve water security. Qatar General Electricity and Water Company recently commissioned the design of 50 massive reservoirs to be built on five sites. The reservoirs are intended to provide the Middle Eastern state with seven days' strategic water storage to avert potential crises should its giant desalination plants, which supply 99 percent of the country's water, fail. The estimated cost of this project is up to QR 10bn (US$2.8bn) and completion is expected in 2016.

Parsons Brinckerhoff is working with clients in Kuwait and Qatar on the design and programme management of projects that will deliver new and improved sewerage and drainage infrastructure.

In Kuwait, we have been working for the Ministry of Public Works with our joint venture partner, Gulf Consult, on the study, design, and preparation of tender documents for the rehabilitation of sewerage and highway infrastructure in three urban areas of Kuwait City. This project was required, in part, to improve the operation of existing sewerage systems which had been constructed in the 1970s and 80s and incorporated flat pipe gradients. This resulted in low flow velocities that permitted solids to settle out, leading to the production of sulphuric acid and hydrogen sulphide which corroded the existing pipelines made of asbestos cement. These urban areas—Al-Andalus, Gernarta, and Sabah Al-Nasser—cover a combined area of 797 hectares and are home to a population in excess of 90,000 people. The study and design examined approximately 174km (108Mi) of foul and surface water sewers together with associated infrastructure which included 112km (69Mi) of roads, telephone cable network, and street lighting.

In Qatar, Parsons Brinckerhoff is programme management consultant to Ashghal, the Public Works Authority, for the Local Roads and Drainage Programme (LRDP). This US$7.9bn programme comprises the construction and upgrade of local road and drainage infrastructure for 200 projects over a period of five years. The drainage and sewerage works will include: surface water detention tanks, new surface water sewerage conveyance systems, deep tunnels, pumping stations, borewell injection systems, and evaporation basins. The foul sewerage systems comprise pipelines, deep tunnels, and large pumping stations. Other projects, not directly associated with the LRDP, are providing additional infrastructure, such as sewage treatment works for newly developed areas. In addition, each project is required to undertake hydrological studies to determine and mitigate flood risk to the developed and adjacent areas. Due to rising groundwater levels across Qatar, groundwater control systems are incorporated in most projects. Treated sewage effluent systems are also included in designs to facilitate landscape irrigation in the public realm.

Even in transportation and other infrastructure projects, the need to conserve limited supplies of water is part of the design effort. *(See the article, "Water Saving Design for the Abu Dhabi Metro System," by Chris Ma et al. as an example of this.)*

In the Gulf region water infrastructure is being improved in line with ongoing development programmes. However, other parts of the MENA region, in particular Libya, have a legacy of under-investment in water supply and sewerage systems. In Libya, water supply and wastewater systems have fallen into disrepair due to insufficient maintenance and lack of spare parts. Added to this, the level of available renewable water resources is extremely low, infrastructure is aging, there are leakage and pollution problems, and water tariffs are not sufficient to cover investment and operating costs. However, there is likely to be significant investment in water and wastewater infrastructure in Libya in the years ahead.

Most infrastructure programmes in this region are funded from oil revenue and at this point it is worth sounding a cautionary note. The face of the energy market is changing as more and more oil reserves are being identified outside the Middle East and North Africa. North America, because of its shale oil reserves, is expected to become self-sufficient in oil and gas within the next ten to twenty years and will soon become an oil and gas exporter. An abundance of oil on the international market will no doubt eventually have the affect of depressing oil prices and may impact the current ambitious civil infrastructure programmes in the MENA region.

The State of Water in Singapore

by **Philip Tat Keung Wong**, Singapore, +65 6395 6761, wong.philip@pbworld.com

The year 2013 was a watershed year for Singapore. The Singapore government announced through its water agency, the Public Utilities Board (PUB), that it would proceed with some major strategic projects, the most eagerly anticipated being the multi-billion dollar second phase of the Deep Tunnel Sewerage System (DTSS) and the Changi NEWater Plant Phase 2. In addition, an important revision to the Code of Practice (COP) on surface water drainage was also released to address climate change concerns. Before discussing the impacts and opportunities that these projects and the changes in the COP present to the local water market, it is perhaps worth providing a brief history to let readers comprehend just how far Singapore has come on its journey to secure a safe and sustainable water supply.

Since gaining independence in 1965, Singapore has had to face and overcome a number of major obstacles and challenges as it developed from a third world country, with virtually no natural resources, to the modern, vibrant, and successful island nation that it's known to be today. One of the key pillars to its success over the past four decades has been the provision of modern sanitation (100% coverage), efficient drainage systems, and a clean water supply to support the growth of the nation. Singapore's robust and diversified water supply system is known as the 'Four National Taps', which comprise:

- Local catchment (more than two thirds of the island is catchment area with a long-term target of up to 90%);
- Imported water from Malaysia (via an agreement, which expires in 2061);
- Highly purified reclaimed water known as NEWater; and
- Desalinated water.

The current daily water supply needs of Singapore, with a population of 5.4 million people, is 400 million gallons per day (mgd), which is met through a combination of imported water (250mgd), desalination (up to 100mgd), and NEWater (up to 120mgd). With the agreement with Malaysia expiring in 2061 and current daily demand forecasted to double by that time, it's no wonder PUB is investing heavily in all facets of water supply. In fact by 2061, PUB plans to meet 80% of demand (640mgd) through desalination and NEWater, and the rest from other sources (160mgd), the "fifth tap" as it were.

As mentioned above, PUB recently called a consultancy tender for the feasibility study and preliminary design of the DTSS Phase 2 (award likely in early 2014). This was followed by another tender for the construction of the Changi NEWater Plant Phase 2.

- The DTSS Phase 2 project picks up from where DTSS Phase 1 left off and is aimed primarily at serving the western sector of Singapore. The mega-project is scheduled for completion by 2022 and comprises a large diameter South Tunnel (30km in length, 20m to 40m below ground and up to 6m dia.), the Tuas Water Reclamation Plant (800,000m^3/day capacity with ultimate capacity of 1,650,000m^3/day) to handle both industrial and domestic effluent, link sewers (70km in length and 3m to 4m dia.), a deep sea outfall, and a co-located 3000 tonnes per day integrated waste management facility (IWMF). Once the feasibility study and preliminary designs are completed, probably towards the end of 2015, contracts for design-build packages for tunnels, sewers, outfalls, and the plants will be procured progressively.

- Changi NEWater Phase 2, which will be located at the Changi Water Reclamation Plant (integral part of the DTSS Phase 1 project), is scheduled for completion by 2016. The contract comprises a design, build, own, and operate (DBOO) NEWater plant to produce up to 50mgd (228,000m^3/day) of highly purified reclaimed water. When combined with the future water reclamation plant at Tuas (expected to be of similar capacity), the total NEWater supply could meet up to 55% of the country's needs in the future.

In addition to the above projects, PUB recently incorporated new measures in its COP on surface water drainage to address the potential impact of climate change, principally to mitigate the risks and hazards of flooding, exacerbated by rising sea levels. The most significant changes include the raising of platform levels of newly reclaimed land by a metre, and mandating the design and installation of detention tanks for new development sites above a certain size.

It's clear from the above that there will be many exciting opportunities in Singapore within the water sector over the next decade. The capital expenditure for DTSS Phase 2 alone is likely to be between (US) \$3 billion to \$4 billion. We believe PUB will be looking for international contractors who have the capabilities to develop the mega Tuas Water Reclamation Plant and IWMF plants through PPPs.

PUB is constantly exploring new innovations and strategies as it continues its search for that elusive 'fifth tap'. This includes studying the potential of water supply from deep underground aquifers in deep rock formations on the western side of Singapore and the piloting of variable salinity plants (VSPs) using rivulets as potential sources. With thirst as a major driver for innovation, Singapore is mindful of its need to invest heavily to meet its water supply needs now and for the future. This means only one thing—even more work is in the pipeline.

Jonathan Ralph

Jonathan Ralph
Technical Director, Head of Water Engineering
Bristol, UK

Paul R. Jones
Deputy Design Manager, Drainage
Doha, Qatar

Tom Mosquera
General Manager, Water Utilities
Sydney, AUS

Philip Tat Keung Wong
Assistant Vice President
Singapore

Getting Resiliency Right

by **John Boulé,** New York, NY, US, 1-212-465-5113, boulejr@pbworld.com; and
Jennifer Itri, New York, NY, US, 1-212-465-5383, itri@pbworld.com

Introduction

"Superstorm Sandy" was a catastrophic event for the New York metropolitan region in October 2012. But the physical destruction was only the short-term impact. The lasting legacy of Sandy may well be that it caused a rally for true climate change and extreme coastal storm resiliency in the northeast US. Sandy's impact will likely be transformative to capital program planners, designers, and programmers. This article seeks to briefly explain how resiliency ought to be thought about in the context of a major metropolitan area. It describes Parsons Brinckerhoff's growing resiliency capability that will allow us to participate in the movement toward greater investment in minimizing the damages to property and risks to public safety from a future filled with numerous weather and climate threats.

Sandy - The Game Changer

Superstorm Sandy was devastating to the neighborhoods, coastlines, beaches, and critical infrastructure throughout the NY metropolitan area. The damages were estimated to be over $50 billion in New Jersey, New York, and Connecticut alone. During 2013, major cleanup, safety enhancement efforts, and resiliency planning have been undertaken so the immediate response of "replacing-in-kind" can be taken a step further. Building back stronger and better than before is crucial to protecting communities as well as federal, state, city, and infrastructure agency assets, and maintaining our society's operational normalcy and efficiency. This single event served as a "resiliency catalyst", a movement that will continue as resiliency is embedded into design and agency capital and asset management programs and becomes a platform for planning and design initiatives in the future.

Resiliency Defined

Politicians, agency officials, and the public are urgently calling for resiliency. But what is it, how much of it do we need or can we afford, and how do we integrate it into the communities and infrastructure systems that it will help protect without dramatically changing our neighborhoods?

NYC Subway System Flood Control Plan

After severe flooding in the New York City subway system in August 2007, Parsons Brinckerhoff was contracted to identify where the worst flooding occurred, what factors led to this flooding, and the appropriate course of action to implement mitigation. ***While "resiliency" and "mitigation" implementation is not a new concept, Superstorm Sandy reinforced the need to integrate resiliency into the community, state, and federal planning process – for the long-term.***

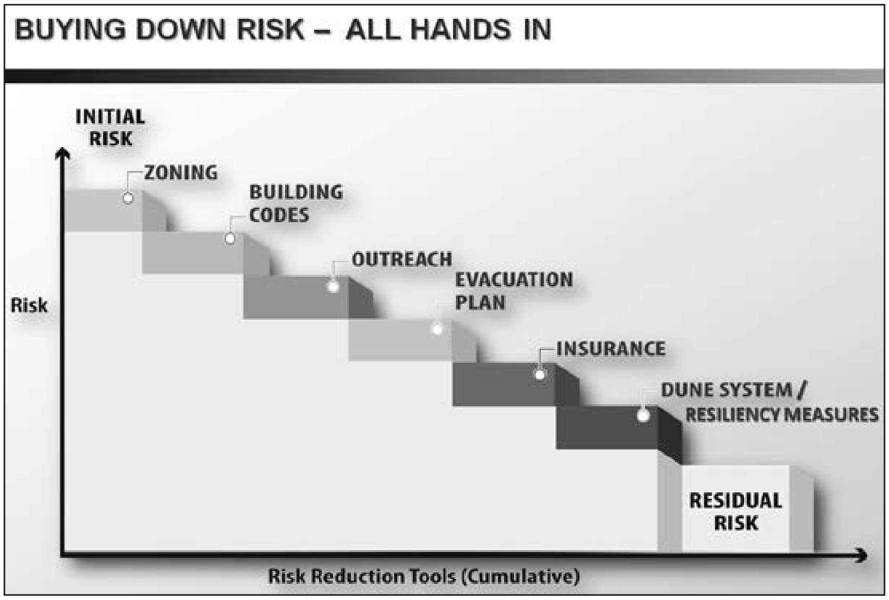
One of the very best definitions of resilience we have found is as follows:

"Resilience: how to help vulnerable people, organizations, and systems persist, amid unforeseeable disruptions. It is important to note that, where sustainability aims to put the world back into balance, resilience looks for ways to manage in an imbalanced world."
(Andrew Zolli, 'Resilience: Why Things Bounce Back').

In the context we are discussing, resilience is about managing risks in an increasingly urbanized world that is likely to be filled with significant sea level rise and increasingly frequent and more powerful storms.

Resiliency = Risk Management

Resiliency can be broken down into one simple, yet complex concept—managing risk. Risk should be managed holistically, by studying ways to reduce it through the cycle of risk management that includes a preparation, response, recovery, and mitigation phase. Building "smarter" with stricter codes, reviewing and modifying current zoning plans in vulnerable areas, being prepared with evacuation plans and fiscally sound insurance coverage, implementing physical measures, all take part in "buying down" risk. Using numerous risk reduction tools in a collaborative and complementary way is how we will pave the road to a more resilient future.

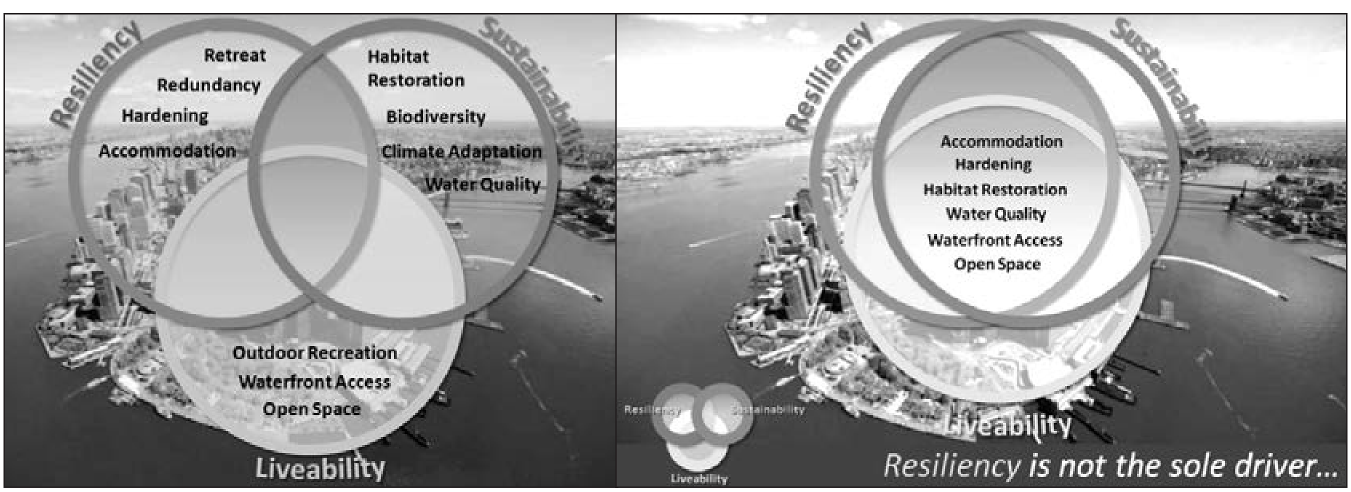


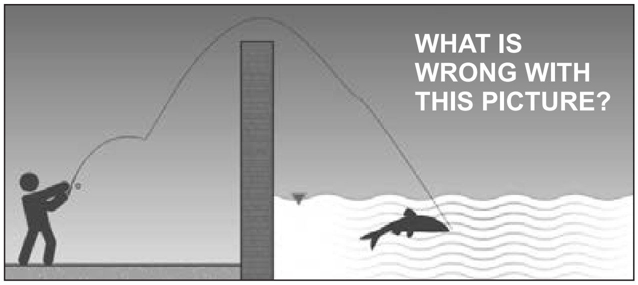
Building the Parsons Brinckerhoff Resiliency Vision - Blending, Layering, and Making Our Recommendations Investment-Worthy

In creating the Parsons Brinckerhoff resiliency vision, we seek to establish a blended, layered, investment-worthy approach to resiliency that is developed by an integrated team of engineers and planners. Blending the resiliency element with sustainability and livability needs makes sense. Although society wants some resiliency—and wants it now because of the mark Sandy left—we should not let resiliency be the predominant and only key design driver. We should fit sound resiliency solutions into the pre-Sandy social and contextual setting. By taking this approach, economic, storm damage prevention, and quality of life goals can be achieved, yielding a triple bottom line (economic, environmental, social) of benefits for the client.

Blending Resiliency into Design

"Sustainability" and "going green", particularly when referring to habitat restoration, climate change adaptation, and environmental protection, have been major components in agency planning initiatives and design strategies. For example, beginning in 2010, the New York City Department of Environmental Protection (DEP) released plans to liberally implement bioswales and green roofs to reduce loading stresses to existing wastewater and traditional storm sewer systems—a primary means to improve New York City's water quality. This wave of blending is expanding beyond the boundaries of just New York City and reaches a regional and global base, addressing more than just stormwater management. Strategies that mix and maximize green with grey infrastructure to reduce storm vulnerabilities must now become part of the way we do coastal risk reduction.





Livability, another term for quality of life, should be integrated into the design and engineering we do. No one wants to wall themselves off from the coastlines we enjoy. We want open spaces, abundant outdoor recreation, and waterfront access—it is part of the culture and identity of so many communities. Before Sandy, especially in the metro NYC area, the foundation for waterfront design was "sustainability" and "liveability" elements. Moving forward, resiliency will take its rightful place as a critical driver, but it cannot replace the other elements, it must be properly blended with them to create a positive triple bottom line formula.

Layering – Resiliency in Time and Space

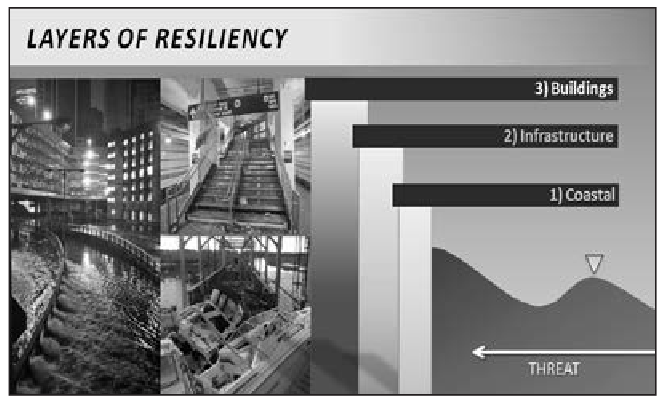
After Sandy, there was an immediate need to address vulnerabilities. Something had to be done right away to deal with the existing threats in a weakened, battered region. Defining and implementing near-term resiliency solutions was the first order of business. But, these interventions had to take a long-term perspective. Engineers would create effective near-term solutions that could be easily translated into long-term fixes. So, engineers and planners worked to build immediate resiliency to manage the risk from potential threats in the 2013 hurricane season, upon us only 7 months after Sandy landed. The near-term solution engineering ("solutioneering") will continue over the next 12 months as the major transit agencies roll-out their requests to reduce risks to their massive at-risk asset portfolios.

Simultaneously, engineers need to focus on the spatial context:

- How can risk management of climate change and extreme coastal storms be broken down in a way that will give a community, municipality, megacity, asset system, or region the lowest residual risk?
- Can we create an in-depth defense that will allow our existing society to persist without significant breakdown, or to rebound quickly thereby avoiding disruption or collapse?

The way to do that is to think in layers. Layers that, when combined, lead to an acceptable and manageable risk level. A suggestive area-wide framework is to define the "layers of resiliency" in a three-ply manner—coastal, infrastructure, and facilities.

It is imperative that Parsons Brinckerhoff considers resiliency from this perspective of a defense in-depth. To do so, we need to be aware of regional, local, and agency plans and to properly nest our resiliency solutions with these plans, thereby optimizing the risk reduction. This task is accomplished by continuing to seek and deliver integrated planning and engineering solutions that support federal, transportation, power, transit, city, state, and community efforts.



As a multi-disciplinary firm, Parsons Brinckerhoff is well-positioned to establish collaborative teams that operate under one common operational picture. Many examples exist of how we have been planning and engineering layered solutions:

1) Coastal

Under contract with the New York City Economic Development Corporation (NYCEDC), Parsons Brinckerhoff was deeply involved in the development of the mayor's plan, "A Stronger, More Resilient New York", which identified over 250 flood mitigation/resiliency initiatives. Engineered beaches (including sand dunes), bulkheads, in-water surge barriers, constructed wetlands, groins, and on-site deployable floodwalls are all examples of either a singular coastal protection system (should only one measure be required) or could be used in combination for an integrated protection system—creating greater levels of safeguard.

2) Infrastructure

The infrastructure layer can be further broken down into three layers of defense:

- Ingress Prevention – Invest your biggest effort in keeping water out. Flood gates and walls, vent grate inserts and cover panels, equipment hatches and backwater valve installation—are some of the many potential alternatives to prevent water entry and to mitigate the most debilitating damage.
- Compartmentalization and Water Removal – The primary goal here is to manage and contain water should it infiltrate through the first line of defense. Isolating parts of facilities to be able to manage the problem and then designing sound pumping and emergency generation systems are crucial to minimizing the damage and returning to normal operations as soon as possible in the response and recovery phase after a storm.
- Critical Space Protection – There are critical spaces within infrastructure assets that, if flooded, would cause crippling effects on infrastructure. Examples may be server centers and electrical distribution rooms. Loss of the equipment inside these spaces would bring an asset down for a very long time. For these few areas, implementing submarine-like defensive measures that establish watertightness is crucial to protecting the equipment that allows day-to-day operations to continue.

3) Buildings

Protecting buildings and facilities with a multi-layer approach is an effective way to ensure that these facilities can be quickly reoccupied and used for their intended purpose and also minimize the economic loss to the activities that are housed within them. The same three-layered approach described for reducing risks to infrastructure can be applied to buildings. Whether protecting hospital emergency generation systems, school server rooms, or facility signal locations, choosing the most economically-sensible solution for a building is also a factor. Parsons Brinckerhoff employed this methodology for the New York City Health and Hospitals Corporation (NYCHHC) in the aftermath of Superstorm Sandy, including: Coney Island Hospital (Data Center Relocation) and Bellevue Hospital (Generator Replacement, Redundant Pumping System, Back-Up and Power Distribution).

New York City Transit (NYCT) Rehabilitation and Flood Mitigation/Resiliency at South Ferry Station

Parsons Brinckerhoff is assessing storm damages, restoring the station with an accelerated design and construction schedule, and developing strategies to protect NYCT's property, equipment, and employees from future flooding resulting from a storm surge threat. This includes implementing near-term and long-term resiliency measures for ingress prevention (such as designing a new entrance that can be quickly "buttoned-up" like the one above), compartmentalization & water removal, and critical space protection.

New York Rising Rebuilding Program for New York State

As part of a team, Parsons Brinckerhoff was chosen for a program to provide additional rebuilding and revitalization assistance to communities severely damaged by Superstorm Sandy, Hurricane Irene, and Tropical Storm Lee. A team of planners and engineers work together to prepare locally-driven recovery plans to identify innovative reconstruction projects and other actions, not only to survive, but to thrive in an era when natural risks will become increasingly common.

Making Resiliency Investment Worthy: Benefit–Cost Analysis

High-cost resiliency solutions can theoretically be produced that will nearly eliminate risk except in the most extreme cases. However, many of these schemes will be unaffordable and unacceptable to communities and policy leaders. Parsons Brinckerhoff's resiliency skill set must include the ability to formulate feasible, economically sound resiliency solutions. A forward-looking perspective is needed, which considers the future threats from climate change and is able to evaluate the benefits of different combinations of blended and layered solutions and to compare them with the costs of implementing and maintaining these interventions over the project lifecycle. Creating the tools and planning skills to do this work quickly or to a greater level of depth over the long-term will support Parsons Brinckerhoff's growing resiliency capabilities. Parsons Brinckerhoff's analysis of alternatives should clearly demonstrate which plan formulations have the highest benefit-cost ratio and greatest return on investment for our clients.

Integrating Planning into Engineering Design

Building resiliency into the context of the social community in a timely and efficient manner requires the overlapping and integration of effective planning with the appropriate engineering solutions. Having both planning and design "cultures" blend, with the same objectives at hand, enables success in a highly abbreviated project time scale, as a sound feasibility analysis can be executed to a "decisionable" level of detail that will push projects forward to full engineering design and construction. Creating deployable, combined, planning and design teams that are able to efficiently work together will complete the fourth key component of the Parsons Brinckerhoff resiliency practice area. This blending of skill sets will also set the conditions for incorporating process and product innovation into the project at the appropriate time to meet client needs and expectations.

John Boulé *is Parsons Brinckerhoff's Resiliency Director. After a distinguished career in the US Army Corps of Engineers, he joined Parsons Brinckerhoff and has managed the enterprise Post-Sandy Recovery and Rebuilding Program.*

Jennifer Itri *is a Senior Marketing Coordinator and Resiliency Deputy Director and is responsible for resiliency client relationship management in Parsons Brinckerhoff's New York office.*

Seepage and Stability Assessments of Two 80-Year Old Embankment Dams

by **James Parkes**, Baltimore, MD, US, 1-410-843-3306, Parkes@pbworld.com

Introduction

Eagle Mountain Lake, near Fort Worth, Texas, is impounded by two embankment dams constructed in the 1930s: the Main Dam and the Spillway Dam. The Main Dam is 85 feet (26m) high and 4,400 feet (1340m) long (Figure 1), and the Spillway Dam, which includes the spillway structures, is 60 feet (18m) high and 3,480 feet (1060m) long (Figure 2). Parsons Brinckerhoff recently performed a comprehensive seepage and stability assessment of both dams as part of a proactive management strategy by Tarrant Regional Water District (TRWD) for its existing infrastructure. Although there were no specific areas of concern, TRWD wanted to have confidence in another 80+ years of performance. The assessment included a desktop study, preliminary models, an investigation program, final models, and development of upgrade measures. The modeling phases also included use of a reliability assessment.

Desktop Study and Analysis

The desktop study included a comprehensive review of construction documents including photos, correspondence, progress records, inspection reports, and bid records, as well as historic construction practices. This type of review had not previously been performed for these dams and the findings were significant.

Both dams consist of earth embankments constructed on soil foundations. Foundation conditions include a surficial layer of clay alluvium underlain by Terrace sands overlying sandstone (the Paluxy formation[1]). Both dams include a "puddled" clay cut-off trench excavated into the foundation, and steel sheet piling driven through the trench to the top of bedrock to form a seepage cut-off through the foundation sands. At the Spillway Dam, sheet piling was only used in a limited area where bedrock was deep. In other areas, bedrock was shallow enough that the cut-off trench could be extended to the top of bedrock.

A key finding was that the Main Dam was built using a combination of hydraulic fill and wetted and rolled construc-

Figure 1 – Aerial View of Main Dam

[1]The Paluxy Formation is a regional geologic formation in the Fort Worth, Texas area consisting of weakly cemented sandstone bedrock formation.

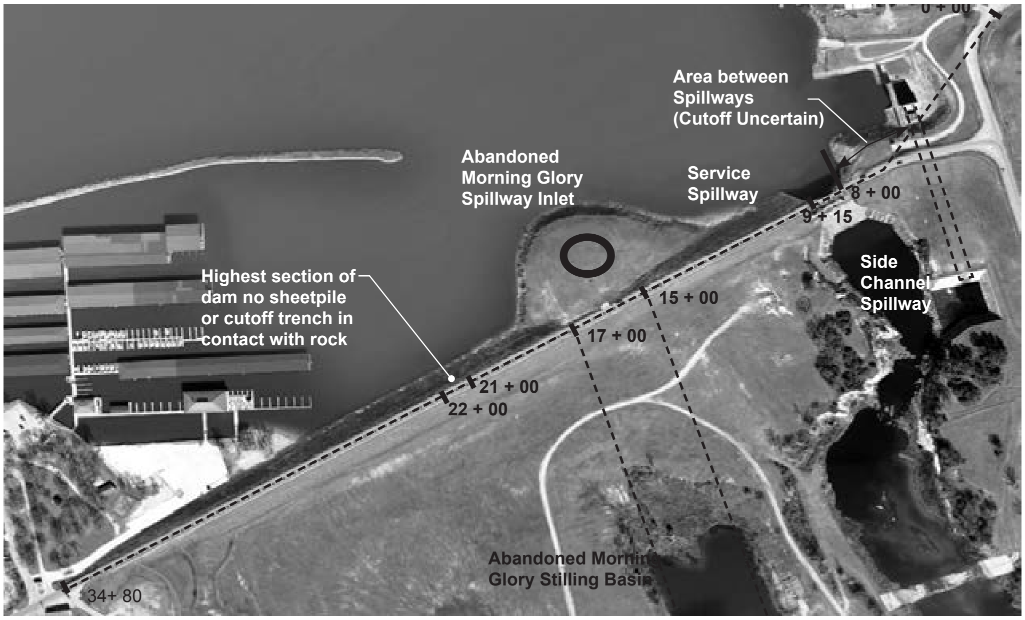


Figure 2 – Aerial View of Spillway Dam

The construction is significant because it influences the internal dam geometry, material types, strengths, and permeability. The document review provided an accurate understanding of the internal geometry and anticipated soil properties. The interpreted internal geometry is shown on construction progress sections for a hydraulic fill section and a wetted and rolled section in Figures 3 and 4. The Spillway Dam was constructed using wetted and rolled techniques, similar to Figure 4.

tion. Hydraulic fill involves placing embankment fill using a flowing stream of water; layers of fill are placed by sluicing the soils from the outer edges of the embankment. This is a historic method of construction generally no longer used for dams, but was common before modern earthwork equipment was developed. Wetted and rolled construction consisted of placing soils in layers and rolling it with trucks, similar to modern earthwork practices.

Another key finding was the existence of gaps or "seepage windows" in the foundation cut-off at the Spillway Dam. A "window" of 215 feet (66m) was found to exist between the western limits of sheet piling and the point where the cut-off trench contacted bedrock. Another "window" was found in an area where the sheet piling did not extend deep enough to reach the top of bedrock. These areas provide preferential and uncontrolled seepage paths under the dam.

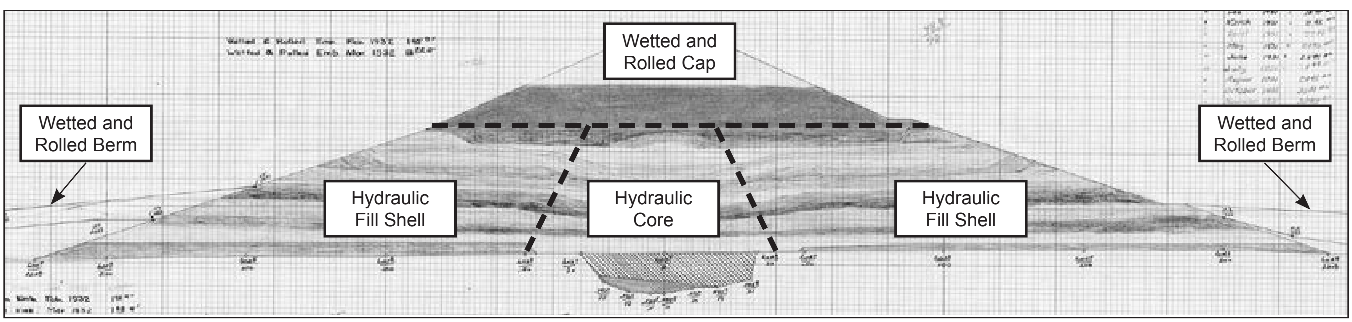


Figure 3 – Construction Cross Section of Hydraulic Fill Section (approximate material boundaries indicated) (Main Dam only)

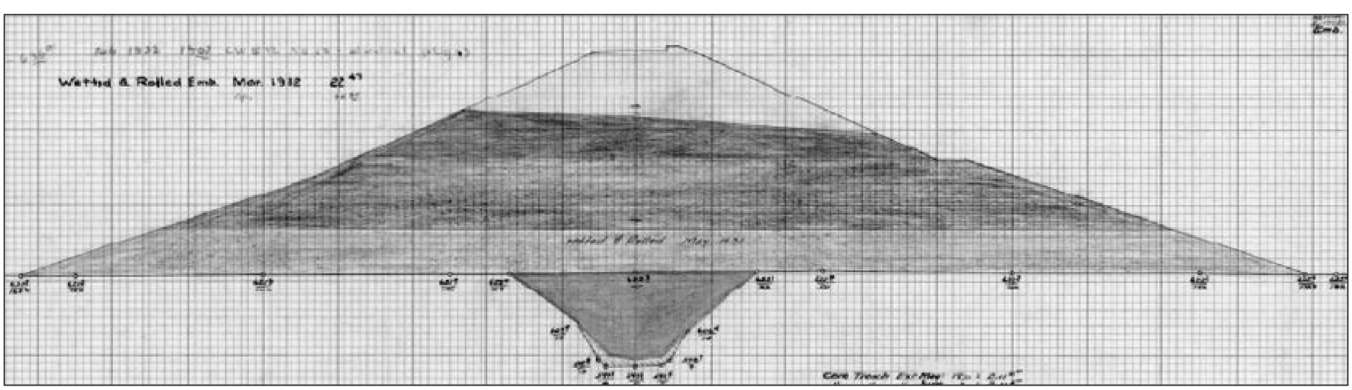


Figure 4 – Construction Progress Cross Section of Wetted and Rolled Section (Portions of Main Dam and all of Spillway Dam)

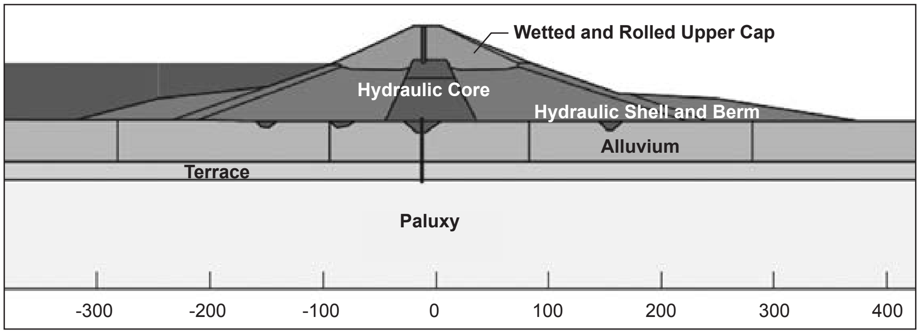


Figure 5 – Preliminary Model of Main Dam Hydraulic Fill Cross Section

Preliminary seepage and global stability models were assessed under conservation pool (normal lake level) and Probable Maximum Flood (PMF) conditions. Results for the Main Dam are summarized in Table 1. The reliability assessment (determination of P(f)) was performed for the most critical (lowest FS value) section.

Preliminary Models

Preliminary models were developed based on the results of the document review. A hydraulic fill section of the Main Dam is indicated in Figure 5. Numerical data for the engineering parameters (shear strengths, etc.) were limited because construction pre-dated modern testing procedures. Therefore, the models contained a significant amount of uncertainty with regard to parameters. A reliability analysis was performed to quantify this uncertainty.

The reliability analysis consisted of performing a First-Order-Second-Moment (FOSM) approach. In this approach, any parameter or geometric boundary that was considered to contain uncertainty was treated as a variable in the models. For each parameter, statistical moments were assigned defining the most likely value and the absolute possible minimum and maximum values. The FOSM approach allows for the calculation of a reliability index, a probability of failure (P(f)), and provides sensitivity results for each parameter. The sensitivity results can also be interpreted as overall contributions of each parameter's uncertainty to the factor of safety (FS). This contribution is extremely valuable in focusing future investigations on soil units and parameters that will reduce the uncertainty in the factor of safety, or on focusing upgrade or remediation measures so that the improvement produces the greatest impact on the FS.

Station	*Cross Section Description*	*FS_{PMF}*	*P(f)*
24+00	Highest wetted and rolled section	1.73	
30+00 – 37+00	Highest hydraulic fill section over thickest foundation clay layer	***1.61***	***0.162***
39+00	Highest hydraulic fill, bypass channel section	1.74	
41+00	Highest hydraulic fill, original river channel section	1.77	

Table 1: Summary of Preliminary Model Results for PMF Conditions at the Main Dam

Although the FS values appear reasonable, which was consistent with the history of performance of the dam, the reliability analysis indicated a probability of failure, P(f), of over 0.1, which is considered much too high for such a structure. The US Bureau of Reclamation indicates that P(f) values of 0.001 or 0.0001 are being used for evaluating dams and risk. Risk analyses are considered advisory, not hard criteria, and must consider site-specific considerations, age and performance of the dam, engineering judgment, etc. (Bureau of Reclamation, 2011). Therefore, the models contain too much uncertainty to be relied upon as a final assessment.

The reliability assessment was also used to evaluate the sensitivity of the models to individual parameters as shown in Figure 6. Results indicate that the strength of the foundation clay alluvium was the most significant parameter contributing to the P(f), with permeability of the foundation layers also being significant. Geometric variations (thickness of foundation strata and core width) did not impact the models.

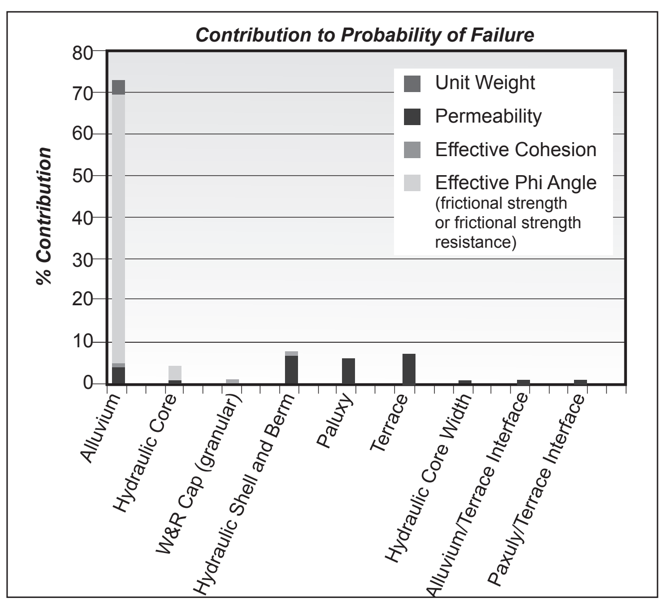


Figure 6 – Contribution to the Probability of Failure for Preliminary Models (Main Dam)

Field Investigation and Testing Program

A multi-phased field investigation was performed for both dams to verify desktop study findings and obtain data for final models. Geophysics, borings, cone penetrometer (CPT) soundings, and aquifer pumping tests were performed. CPTs and borings were used to confirm the internal geometry of the dams, foundation conditions, and obtain data for parameters. Strength testing was focused in the foundation alluvium based on the reliability assessment (Figure 6). Pumping tests were used to investigate the "seepage windows" and determine the permeability of foundation strata.

The geophysics investigation consisted of magnetic surveys, and self-potential (SP) and direct current electrical resistivity imaging (ERI) surveys. These investigations were used to verify the limits of the sheet piling and detect areas of higher water content that are interpreted as preferential flow paths ("seepage windows").

The geophysics investigation at the Spillway Dam verified the existence of seepage anomalies at the suspected "window" locations as shown in Figure 7. Water chemistry testing from recovered pumping test discharge at the toe of the Spillway Dam near one of these "windows" indicated a direct connection (ineffective cut-off) between the lake and the downstream foundation soils.

Final Models and Analysis Conclusions

Investigation results were used to confirm and update preliminary models, including selection of critical sections and determination of minimum, maximum, and most likely values of parameters. A reliability assessment was performed on the final models. Results for the Main Dam, presented in Table 2, indicate acceptable FS and P(f) values.

Station	*Cross Section Description*	*FS_{PMF}*	*P(f)*
16+00	Hydraulic fill section, highest foundation pore pressures	1.59	$3.5*10^{-5}$
30+00 – 37+00	Hydraulic fill, highest embankment section	1.53	$1.3*10^{-5}$

Table 2: Final model results for hydraulic fill sections under PMF (Main Dam)

Although final FS values are less than preliminary values, the final P(f) is significantly lower and within commonly used limits. The lower P(f) values for the final models are an indication that there is much less uncertainty in the final models (due to the data collected in the field investigation) than in the preliminary models. Comparing Table 1 and Table 2 illustrates that the FS alone does not provide a complete understanding of the safety of a dam. A reliability assessment adds a more thorough understanding of the uncertainties involved. In this case, the reliability assessment also helped focus investigation resources for the greatest return and was used to document the im-

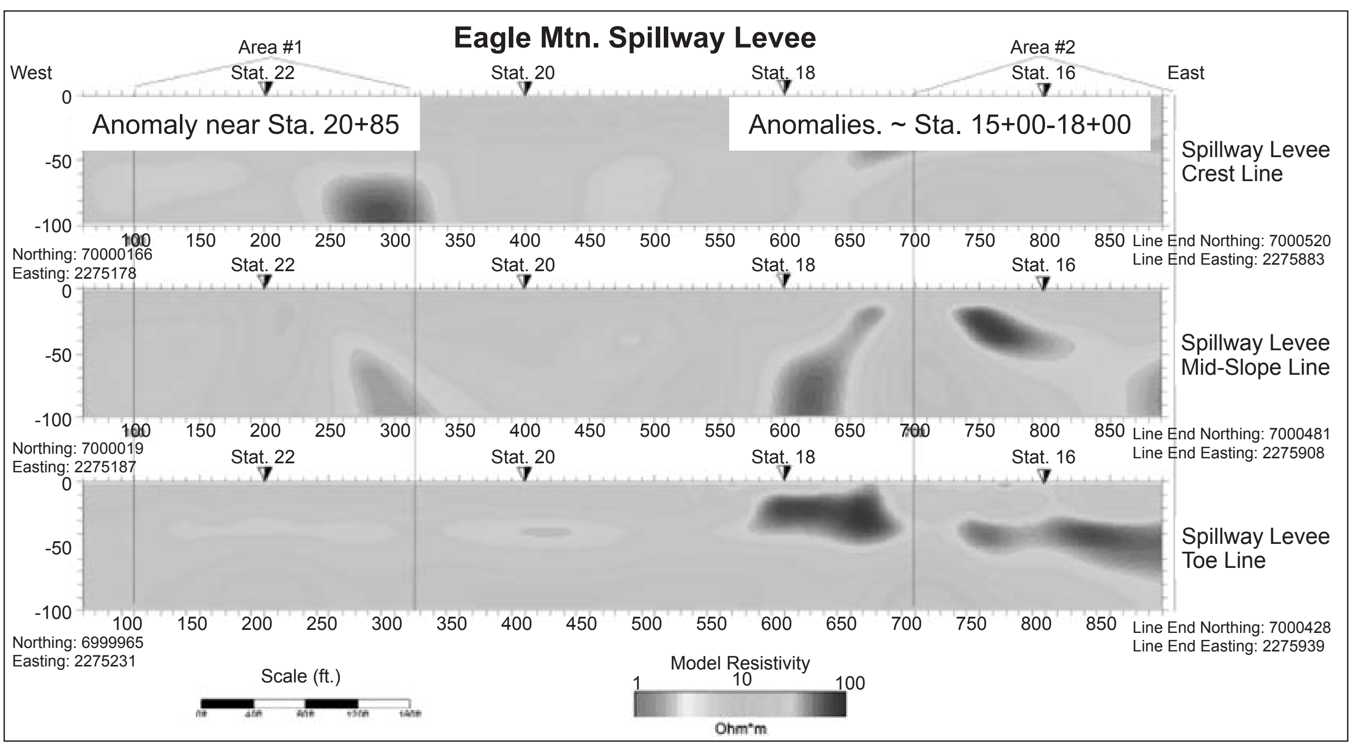


Figure 7 – ERI Investigation results showing preferential seepage paths (Spillway Dam)

provement in the overall assessment by comparison of the preliminary and final P(f) values.

Closure of Seepage Windows

For the Spillway Dam, the models were updated and used to assess the impacts of the "seepage windows" on stability. Upgrade concepts to create a continuous foundation cut-off (close the "windows") were evaluated. A permeation grout program using liquid chemical grout to create an impermeable barrier within the foundation sand was chosen. This program could be performed with small equipment which would allow the roadway on the crest of the dam to remain open and could be targeted to the areas with the "windows", thus minimizing costs.

Test Grout Program

A test grout program was performed at Sta. 16+00, at the pump test location. This allowed for a pre- and post-grout comparison of permeability. The test program provided an assessment of the feasibility of the grouting, an assessment of grout injection systems, and development of requirements for assessing grouting effectiveness.

A chemical grout was selected based on the sandy nature of the soils. The grout had to be capable of forming an impermeable barrier that is biologically and chemically inert, unaffected by filtration, and is environmentally safe. The grout also had to be able to expand beyond its liquid volume in order to create a complete cut-off including tying into and overlapping the existing cut-off measures.

Grout Curtain Construction

The construction grout program included four zones, as indicated in Table 3, with several rows of overlapping grout holes as shown in Figure 8. These zones overlapped the limits of the seepage windows, except between the spillways where the limits are defined by the spillway structures. The grout-hole pattern provided maximum spatial and depth coverage, and the extension of the grout zones beyond the limits of the windows provided overlap between the existing cut-off measures and the grouted soils. An extra treatment area, Zone 3, was added at the west side of the service spillway. Although no seepage was noted here, in general, areas next to concrete structures often form preferential flow paths. It was considered good practice to grout this area as a precautionary measure.

Construction of the grout curtain was performed by Hayward Baker, Inc. of Fort Worth, Texas for a cost of approximately $4 million (US). Approximately 55,000 gallons of grout were used. The reduction in permeability was verified using falling head tests and a post-construction pumping test. Results of the pumping test indicated a significant reduction in subsurface permeability. Water chemistry testing indicated that a direct connection between the foundation soils at the toe of the dam and the lake water no longer exists. Based on the in-situ testing during construction and the post-construction pumping test results, the seepage windows are considered closed.

Grout Zone	*Station Limits*	*Seepage "window" limits*	*Comments*
Zone 1	20+25 to 23+50	20+85 to 23+00	Gap in cut-off trench and sheetpile excavation
Zone 2	14+25 to 17+75	15+00 to 17+00	Abandoned MG spillway
Zone 3	9+20 to 9+75		West side of service spillway
Zone 4	5+53 to 8+00	5+53 to 8+00	Area between spillways

Table 3 – Summary of Grout Zones at Spillway Dam

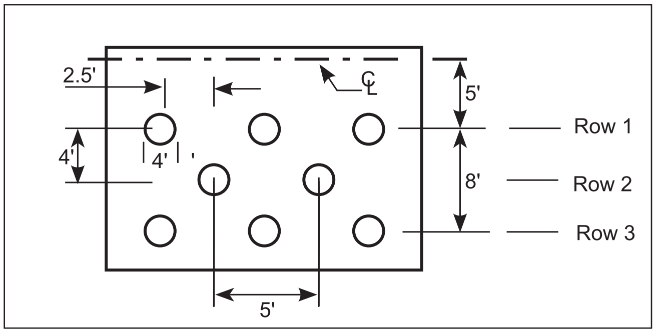


Figure 8 – Grout Hole Layout (Pattern is on the Downstream Side of Dam Centerline)

[This assessment was a team effort including firms Zonge Geosciences, Inc.; LCA Environmental, Inc.; and Prototype Engineering, Inc. Henry Russell of Parsons Brinckerhoff was instrumental in the grouting program's success.]

References

Bureau of Reclamation (2011), "Rationale Used to Develop Reclamation's Dam Safety Public Protection Guidelines," Interim, US DOI, Dam Safety Office, Denver, CO.

James Parkes *is a Supervising Geotechnical Engineer in Parsons Brinckerhoff's geotechnical and tunneling practice. He has worked on a variety of infrastructure projects including dams, tunnels, bridges, and buildings.*

A Forecasting Modelling System to Help Protect the South East of England from the Impact of Flooding

by **Paul Carter**, Godalming, UK, +44(0)14 8352 8737, carterp@pbworld.com; and
Alan Knott, Manchester, UK, +44(0)16 1200 5151, knott@pbworld.com

The Environment Agency of England and Wales[1] (the Agency) was established "to protect and improve the environment" and make it "a better place for people and wildlife." Its Corporate Plan 2011-2015 includes the following theme: "to reduce the risks to people and properties from flooding."

Over 5.5 million properties in England and Wales, or one in six, are at risk from flooding. The latest UK Climate Projections 2009 (UKCP09)[2] indicate that rising sea levels and increasingly severe and frequent rainstorms mean the risk of floods will increase for people, communities, and key infrastructure like roads, railways, power sub-stations, and water treatment plants.

The Agency's South East Region (see Figure 1), created by integrating the former Southern and Thames Regions, has 781 miles of coastline and 2,212 miles of main rivers with 668,900 properties at risk of surface water flooding and 403,000 properties at risk of flooding from rivers and the sea. The South East Region, like others across the UK, has experienced a number of severe flood events as well as periods of water shortages over the last two decades. The need for additional tools to help the region forecast river and sea levels, and thereby be better able to warn the population of likely events, has been recognized. Also recognized is the need to manage water resources and flood defence assets to mitigate flood and drought risk and to obtain the best outcome for people and their property.

This article provides an introduction to the management of flood events and the conceptual framework introduced by Parsons Brinckerhoff as part of a National Flood Forecasting Modelling System Strategy. The article also explains how the Southern Region Flood Forecast Scheme (SuRFFS) was implemented.

Figure 1 – Map showing the location of the Environment Agency's South East Region

Managing Flood Risk

Although the risk of flooding cannot be completely eliminated, the Agency seeks to minimise the effects of flooding and reduce the damage it causes by working with stakeholders (e.g., utilities, local authorities, central government, emergency services, and contractors) to:

- manage land and river systems;
- build and maintain flood and coastal defence;
- raise the awareness of flood risk through flood mapping;
- encourage people to take action to protect themselves and their property;

[1]From 1st April 2013, Natural Resources Wales took over responsibility for environmental matters in Wales.

[2]UKCP09 is the fifth generation of climate change information for the UK, and its projections are based on a new methodology designed by the Met Office. Climate science and computer modelling have advanced significantly - UKCP09 reflects scientists' best understanding of how the climate system operates, how it might change in the future, and allows a measure of the uncertainty in future climate projections to be included.

- take effective control of development on flood plains; and
- provide flood warnings and work with emergency responders to help people who are at risk.

To accomplish this, and as part of the National Flood Forecasting Modelling System Strategy, Parsons Brinckerhoff worked with the Environment Agency, providing strategic advice and support in specifying a real-time operational systems framework which is described below.

Operational Systems Framework

This operational systems framework is strongly related to the natural cycle of an environmental 'event' (e.g., a flood) which progresses from detection to clearance. The framework is based on 3 major concepts:

1. **High Quality Data** – provides current, historic, and future (forecast) data which is reliable and accurate. This refers to the quality of both input and resulting output, or forecast, data. A model can be compromised by poor quality input data or by poor calibration when it is set up and will not then be able to produce a high quality output, or forecast;
2. **Openness** – allows for modular development and progressive upgrade or replacement. This system allows models of different types produced by different suppliers to be run to produce flood forecasts. The system is open because the model interface is declared in a published document which is available to all model suppliers, so the model platform is not locked into a model from one supplier; and
3. **Flexibility** – can be adapted to changes in requirements and technology and is 'scaleable'.

The activities in the natural cycle of an environmental event are:

- *Detection* – identification of conditions (often achieved through receipt of 'alarms' from telemetry systems) which indicate a potential abnormal situation (e.g., heavy rainfall, high or very low river levels).
- *Forecasting* – providing routine and 'on-demand' prediction (usually by running a simulation model) of future conditions. For flood forecasts this would normally be up to 24 hours prior to occurrence.
- *Warning* – issue warnings and disseminate information to the public and to the emergency services and professional partners (e.g., local authorities).
- *Response* – by the Agency in terms of operating its resources and assets (e.g., pumps, river/sea defences and structures), and mobilising its operations and maintenance workforce; by the emergency services; by businesses and industry; and by the public in protecting themselves and their property.
- *Event Monitoring & Management* – continuous monitoring of environmental factors (e.g., weather, river and sea levels) which contribute to the flood conditions; monitoring forecasts and their accuracy; monitoring the progress of the dissemination of information and warnings and the effectiveness of the response to determine how the event is progressing; and evaluating and managing the performance, as appropriate, of the cycle.
- *Clearance* – determining that the potential incident is not going to occur or that the event has passed. In the case of flood events the cycle can last from just a few hours (normally when the conditions change and a flood does not actually take place) to several days (when adverse conditions persist and widespread flooding occurs).

The stages in the event cycle and their relationship to the operational systems are shown in Figure 2.

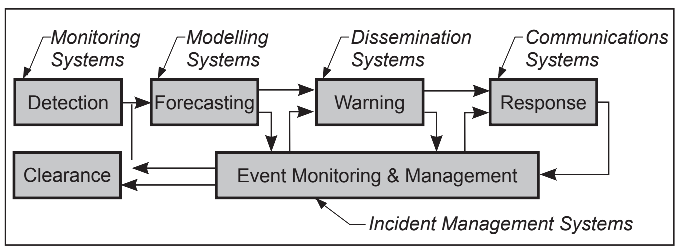


Figure 2 – The Event Cycle: once a potential event is detected the cycle is 'triggered' and is not complete until 'cleared' by one of the subsequent activities.

The Agency uses monitoring, forecasting, communications, data management, decision support, and visualisation systems to manage events and it is important to consider each system individually as well as in the context of other systems with which it is closely connected. The strategic framework for operational systems which resulted from this evaluation is shown in Figure 3. It can be applied throughout the Agency and can be easily tailored for use on different applications (such as for flood, pollution, drought, and river management).

Southern Region Flood Forecast Scheme (SuRFFS)

The Agency's regions throughout England and Wales have been using and further developing real-time flood forecast models for many years. Parsons Brinckerhoff has provided assistance to many of the Agency's national and regional real-time telemetry, flood forecasting, and event management initiatives, including providing project management support to the Southern Region Flood Forecast Scheme (SuRFFS) which set out the following objectives for the flood forecasting model development programme:

- Improve the flow and flood forecasting capability of all areas at risk of fluvial, tidal, and coastal flooding;
- Introduce water level forecasting for all flood warning areas; and
- Introduce inundation mapping for key locations.

One of the main outputs of SuRFFS was the development of real-time river level models for main river catchments throughout the region, where sufficient data had been electronically collected from previous flood events. Many catchments had data recorded during the flooding in the year 2000, for some catchments this included flood return periods in excess of 1:100[3] years.

A ‘model brief’ was developed to define the outputs required (river level forecasts) and the inputs available (real-time rainfall, river level, sea level, river flow data, weather radar rainfall forecasts, etc.) for each of the major river catchments (around 25 were modelled) in the region. The work to develop the models was let to modelling consultants and was divided into the following phases:

- Phase 1 – Catchment Inception Report including data review and detailed model design. The model design included consideration of the priority to be assigned to rainfall inputs available from rain gauges and weather radar forecasts, and the availability and possible use of “updating” of model states based on real-time measurements of the modelled outputs.
- Phase 2 – Catchment Model Calibration Report including development and calibration of rainfall runoff and hydrodynamic river models. Models were calibrated against five selected actual flood events.
- Phase 3 – Catchment Model Verification Report including verification of rainfall runoff and hydrodynamic river models against data from a further three flood events (separate from those used for calibration).

Following initial work, it was found that the scope of work and costs of model development could be controlled more closely by awarding Phase 1 of the work separately from the later phases. This allowed phases 2 and 3 of the model development for each river catchment to be awarded when a full analysis of the data available for the catchment had been undertaken, thereby preventing unnecessary changes of scope and halving the time to develop a typical river catchment model, and increasing the opportunity for competition in the procurement of modelling services.

Development of hydrodynamic models was assisted in many catchments by making use of “donor” models, previously developed for offline purposes using the same modelling software. These models were then streamlined to allow them to run efficiently in real-time. The models were also modified as necessary to allow them to be run for events with a return period of 1:100 years with an additional 20% flow allowed for the increased river flows expected due to predicted changes in the future climate.

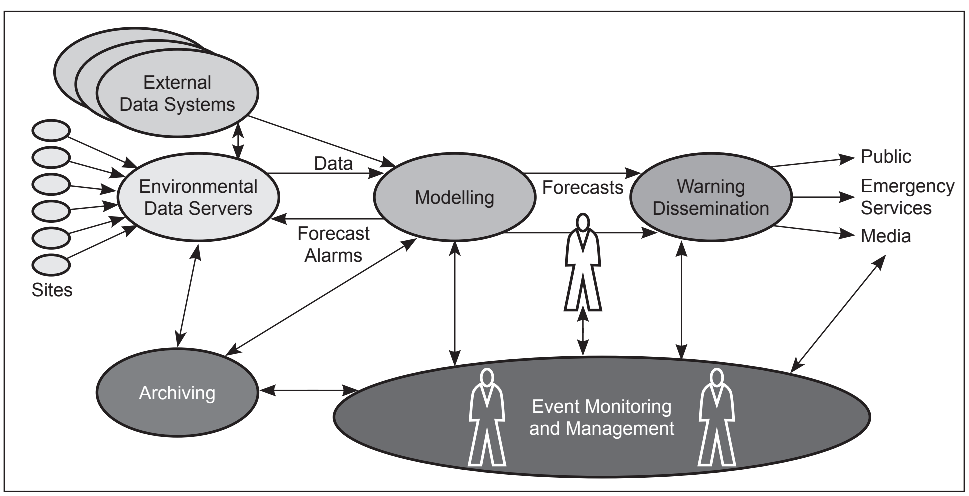


Figure 3 – A Real-time Operational Systems Strategic Framework.

[3]A flood with a 1 in 100 year return period has a 1/100 or 1% chance of occurring in any one year. The Environment Agency defines the following flood risk categories: 1. Significant - more than 1.3 % (1 in 75 chance in a given year), 2. Moderate - 0.5% to 1.3 % (1 in 200 to 1 in 75 chance in any given year), 3. Low – less than 0.5% (less than 1 in 200 chance in any given year) ref. “Flooding in England a National Assessment of Flood Risk” 2009.

Modelling systems used by the South East Region

As part of the Agency's National Flood Forecasting Modelling System (NFFMS) Strategy, the Agency implemented a National Flood Forecasting System (NFFS) to forecast water levels at specific river locations up to 24 hours prior to occurrence. As each of the Agency's regions has historically developed their own flood forecasting systems independently, a wide range of forecasting models and methods were in use. The NFFS uses an "open shell" concept which can run a variety of proprietary and bespoke forecasting models.

The following models are used by the South East Region for forecasting rainfall, runoff, river, and sea levels:

Hydrological Runoff Models – probability distributed model (PDM) supplied by the UK Centre for Ecology and Hydrology (CEH). PDM is a fairly general conceptual rainfall-runoff model which transforms rainfall and evaporation data to forecast water flow at the catchment outlet.

Hydrological Routing Models – kinematic wave (KW) model supplied by the UK Centre for Ecology and Hydrology (CEH). KW is a channel flow routing model designed for modelling and forecasting flow in river channels (natural or otherwise) with lateral inflows.

Hydrodynamic Models (1D) – ISIS is river modelling software used for flood risk management. ISIS makes available 1D and 2D simulation solvers, analysis, visualisation tools, and flood inundation within one environment.

Lookup Table-type Models – model results generated offline by 3D modelling as used in coastal forecasting, for example.

Figure 4 illustrates the concept of "openess' supported by the Agency's NFFS.

Conclusion

The development of the NFFS tool has significantly advanced the ability of the Environment Agency to mitigate the flood and drought risks faced by the people of England and Wales, thereby helping to achieve one of its main objectives. The South East Region has been bringing models developed by the SuRFFS project into operational use to support flow and flood forecasting since 2009. However, assessment of model performance depends to a considerable extent on the incidence of significant rainfall events in the region and it is too early to accurately assess how the models will perform in the event of a severe flood. The operational models have produced extremely useful forecasts in terms of flood warning threshold crossings, when these model outputs have been interpreted by experienced forecasters. The rainfall runoff models have been found to perform better for wetter catchment conditions than for drier catchment conditions. To address this issue, selected rainfall runoff models have been recalibrated, resulting in a reduction of overestimation and, hence, a markedly improved performance in drier catchment conditions. A programme of formal model performance assessments is currently underway which will direct the future development of forecasting models in the region and ensure that the operation and maintenance practices using the SuRFFS tool will continue to improve.

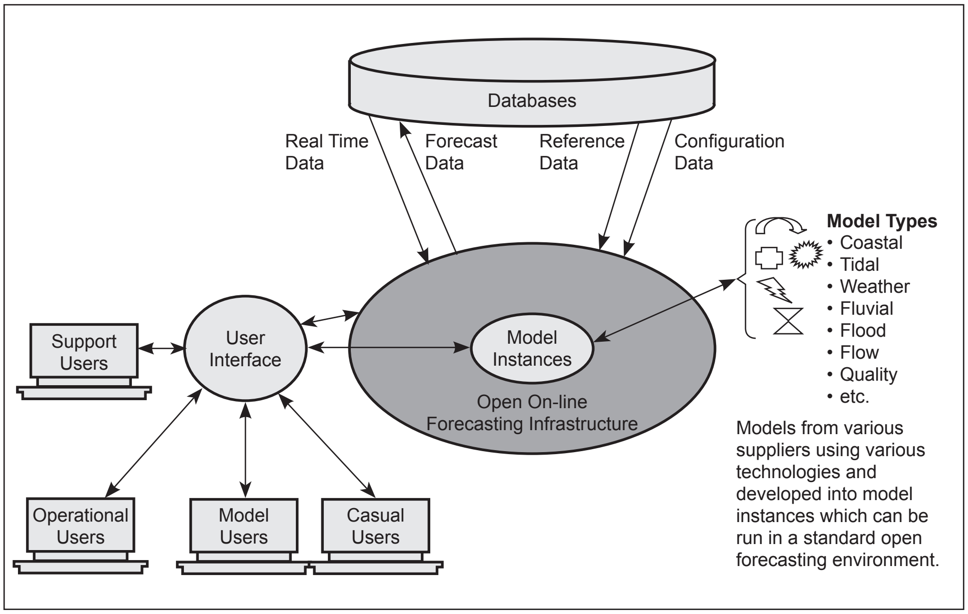


Figure 4 – Openness as applied to the design of the Agency's National Flood Forecasting System. The differences in model types and suppliers are transparent to forecasters.

***Paul Carter**, BSc(Hons) CEng MIET, is a Chartered Electrical Engineer (CEng) and a Member of the Institute of Engineering & Technology (MIET). As Senior Project Manager at Parsons Brinckerhoff, he has undertaken both engineering and project management roles for clients in the water, power, transport, environment, and buildings sectors. He specialises in systems engineering of real-time control systems including Telemetry and SCADA systems.*

***Alan Knott** is a Principal Professional Associate (PPA) and Fellow of the Institute of Engineering & Technology (FIET) and a member of his region's technical leadership team (TLT).*

Groundwater Flooding in South Winterbourne Valley, Dorset

by **Charles Bennett**; Bristol, UK, 0117-933-9300, charles.bennett@pbworld.com

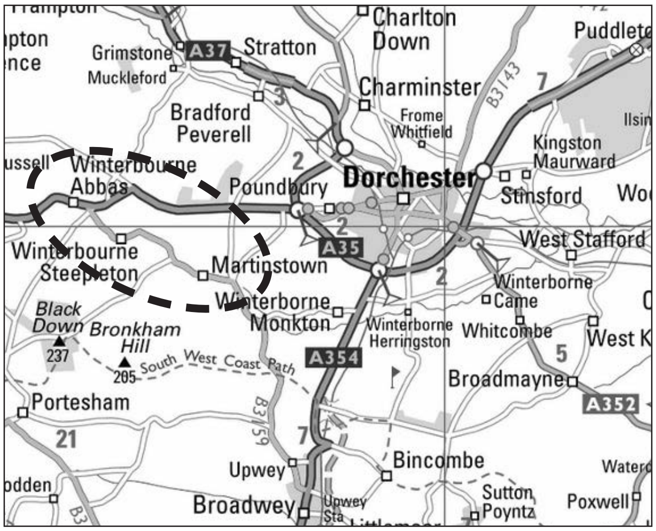


Figure 1 – Study Location

In July 2012 heavy rainfall led to widespread flooding in three villages in the South Winterbourne valley in south west Dorset in the UK. The villages were Winterbourne Steepleton, Winterbourne Abbas, and Martinstown (see Figure 1). Following the flooding, Parsons Brinckerhoff worked with Dorset County Council to identify the causes of the flooding and to identify potential measures to reduce flood risk in the area.

Heavy rainfall on July 6th and 7th, 2012 resulted in groundwater, surface water, and fluvial flooding (see Table 1 for types and sources of flooding).

Rainfall gauges showed that 112mm of rain fell in the 38 hour period between 1 p.m. on July 6th and 3 a.m. on July 8th. The rainfall, assessed using the Flood Estimation Handbook (FEH) methodology, had an annual probability of 1.3% - 2.2%, meaning an event of this magnitude is expected to occur once every 40 - 80 years. High flood levels caused the closure of the A35 trunk road (see Figure 2) which runs through the valley, and 42 properties in the three affected villages suffered internal flooding. Flood levels remained high for over two weeks.

As the lead local flood authority for the area, Dorset County Council led an investigation into the flooding. Parsons Brinckerhoff was appointed to assess the flood risk in the catchment area and to identify flood protection measures and resilience plans for future flood events.

The catchment had suffered significant flooding in the past, notably on July 19th, 1955, when 280mm of rain fell in a 24 hour period. This was a UK record until 2009[1].

Figure 2 – Flooding across the A35 trunk road, July 2012

[1]Shaw et al, 2011. Hydrology in Practice. 3rd Edition. Oxford: Spon Press

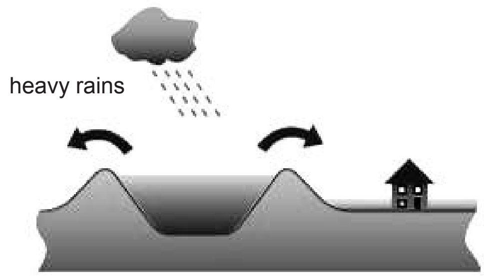
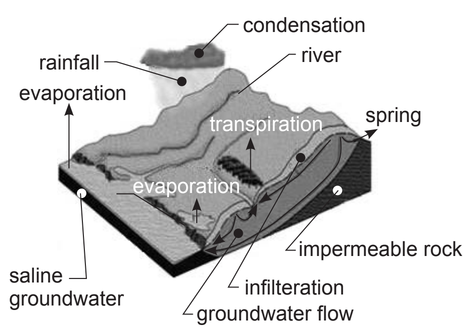
Flood Source	Example
River (or fluvial) flooding: occurs when the flow in a river or watercourse exceeds the capacity of the river channel and causes overtopping or a breach. It can happen, for example, when heavy rain falls on an already waterlogged catchment. A blockage caused by natural material or manmade objects/litter can also cause rivers to overtop their banks.	
Surface water (or pluvial) flooding: flooding caused by intense rainfall, which exceeds the capacity of the installed drainage system. This type of flooding is typically localised and happens very quickly after the rain has fallen.	
Groundwater flooding: occurs when water levels in the ground rise above surface levels. It is most likely to occur in areas underlain by permeable rocks or granular layers, called aquifers.	

Table 1 – Types and sources of flooding

Factors Contributing to Flooding

Factors contributing to the flood risk in South Winterbourne were assessed using archived records of the different flooding events within the catchment, which included photographs of the flood events, rainfall records, flow data from the South Winterbourne stream, and data from groundwater monitoring boreholes.

Accounts of the flooding were obtained from residents of the three villages through two 'flood forums' held locally. These were followed up by selected interviews with affected landowners and residents. The views of Wessex Water, the local water supply and sewerage service provider, and the UK Environment Agency were also obtained.

A key factor contributing to flood risk in the catchment is the underlying geology of the area. South Winterbourne takes its name from the ephemeral chalk stream or 'winterbourne' that flows through the valley. A winterbourne is a stream or river that is dry through the summer months, and a high proportion of flow in winterbourne streams —and sometimes all—is of groundwater that emerges from the chalk bedrock in the lowest parts of the valleys.

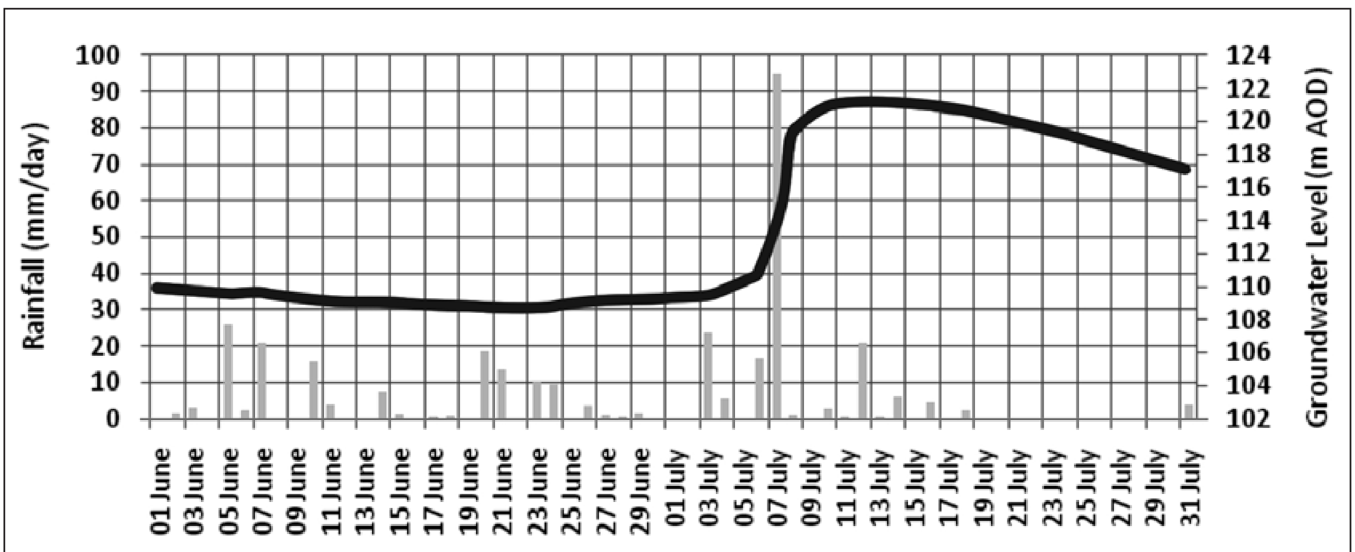


Figure 3 – Groundwater level (thick line) to rainfall (vertical bars) in the South Winterbourne catchment, June–July 2012

Figure 4 – Constrictions to the conveyance in the channel due to its constrained position between houses and the road, and from numerous low structures in the channel.

Steeply sided winterbourne valleys are particularly susceptible to groundwater flooding. The fractured nature of the chalk allows rapid infiltration to the water table, resulting in rising groundwater levels, greater groundwater emergence, and higher fluvial flows.

Analysis of groundwater records in the catchment over the period of the most recent flooding indicated a sharp rise in groundwater level directly following the 112mm of rain that fell on July 6th–8th, 2012. Recorded groundwater levels rose 8.78m between July 7th and 8th (see Figure 3).

Other factors contributing to the flooding included reduced flow capacity in the stream from dense vegetation, low bridges, and localised constrictions in the channel (see Figure 4). The intense rainfall on saturated ground also led to high volumes of surface water runoff from agricultural land.

Recommendations

A range of measures were considered to alleviate the flooding in the affected villages, from catchment scale approaches to individual household level protection. Catchment wide approaches, such as the construction of flood relief culverts or diversion schemes, would not be feasible for the relatively small number of properties at risk of flooding in the study area. Due to the immense volumes of groundwater, approaches involving large-scale groundwater pumping would be technically impracticable.

Instead, household flood protection approaches in coordination with improved management and maintenance of surface water infrastructure and improved awareness of groundwater flood risk were identified as the best approaches for the management of future flood risk in the catchment. Due to the combined risk from groundwater and overland flow, effective household protection measures would need to combine threshold protection, such as doorway flood barriers, with drainage measures to lower the local groundwater level (see Figure 5).

The formation of a community flood action group was recommended to support the approaches above, with the objective of creating a representative voice for flood concerns in the community. The group would help to coordinate local measures to reduce flood risk and prepare for the event of future flooding. Some of these measures include improved maintenance of the watercourse, and the preparation of personal and community action plans to be implemented in the event of forecasted periods of high flood risk.

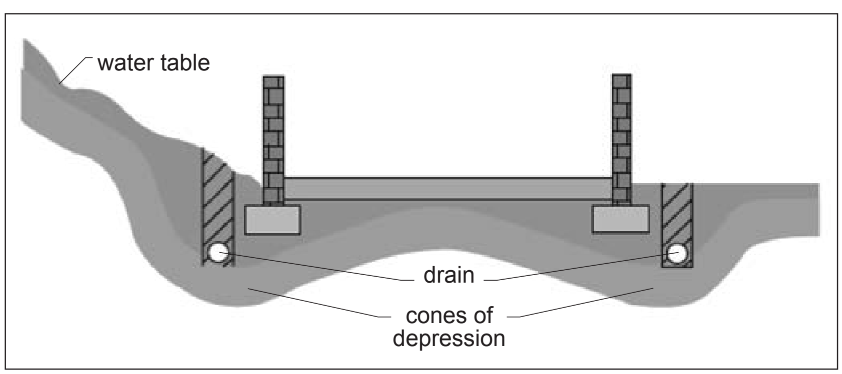


Figure 5 – Example of improved drainage to create a 'cone of depression' to prevent groundwater emergence. Improved drainage allows groundwater to drain by gravity away from the building, lowering groundwater levels locally.

Specific recommendations to help alleviate localised flood issues in each of the three villages were also made. These included removing obstructions to flow in the watercourse, such as low access bridges, and the restoration of disused secondary channels to increase above-ground storage and conveyance.

Conclusion

This project illustrates the potentially devastating impact of groundwater flooding. The extended duration of groundwater flooding and widespread misunderstanding of the underlying causes can worsen the impact in affected communities.

In areas with susceptible geology, such as South Winterbourne, the volume of flood water that can arise following a sharp rise in groundwater can be so large that realistic options for alleviation are limited. As a result, the best approach to protect people and property may be to advance community resilience through improved maintenance and better coordination of emergency response.

This was the approach recommended in South Winterbourne, with a key recommendation being the formation of a community flood action group to empower the community to improve their own flood resilience.

The recommendations have been presented to the community and initial meetings have taken place to initiate the formation of a flood action group.

Charles Bennett *is a Civil Engineer and part of the Parsons Brinckerhoff water engineering team in the UK. He works on a range of projects relating to water management and flood risk.*

Tidal Power – An Emerging and Predictable Source of Energy

by **Peter Kydd**, Bristol, UK, +44 (0)117 9339 232, kyddp@pbworld.com

Water engineering is normally considered to comprise water supply, wastewater, and flood alleviation. However, tidal power draws on many water engineering and environmental skills. Parsons Brinckerhoff has been working on a number of significant tidal power studies over the past five years which will be of interest to the water engineering community.

Tidal power remains one of the great engineering challenges yet to be fully exploited in the modern world and yet it was first mooted more than a century ago. The oceans hold enormous amounts of potential energy which can be developed with very low greenhouse gas emissions. There are three main types of energy that can be captured from the oceans: wave, tidal stream, and tidal range. Wave energy holds significant global potential but is the most challenging in engineering terms. Tidal stream and tidal range rely on high tidal currents and tidal range respectively and their potential is limited by the availability of suitable sites. Nonetheless, in the UK alone, there are some 15–20GW of tidal energy that could be captured (enough to satisfy 10% of the UK's current energy demand). Other global tidal power hotspots include the US, Canada, France, Russia, and Korea. This article focuses on the different tidal technologies and the ongoing work and opportunity that the sector brings, alongside the many challenges that will need to be overcome along the development journey. It focuses not just on Parsons Brinckerhoff's experience in the sector, but also the wider industry and stakeholder perspectives.

Tidal Range

Tidal range is the most mature of the technologies, essentially using modified hydropower turbines and significant civil engineering works to impound a body of water and generate power using the head difference created as the tide ebbs and floods. France led the way with tidal range development back in the 1960s and La Rance[1] (near Saint-Malo in Brittany) was the world's first and, until 2011, largest tidal power plant with an installed capacity of 240MW. Some 45 years later, the original turbines are still in use and the plant is one of the cheapest forms of power generation on the EDF Energy network. Since then, tidal range power development has progressed somewhat erratically. The UK has studied many sites, in particular the Severn Estuary[2] (see Figure 1).

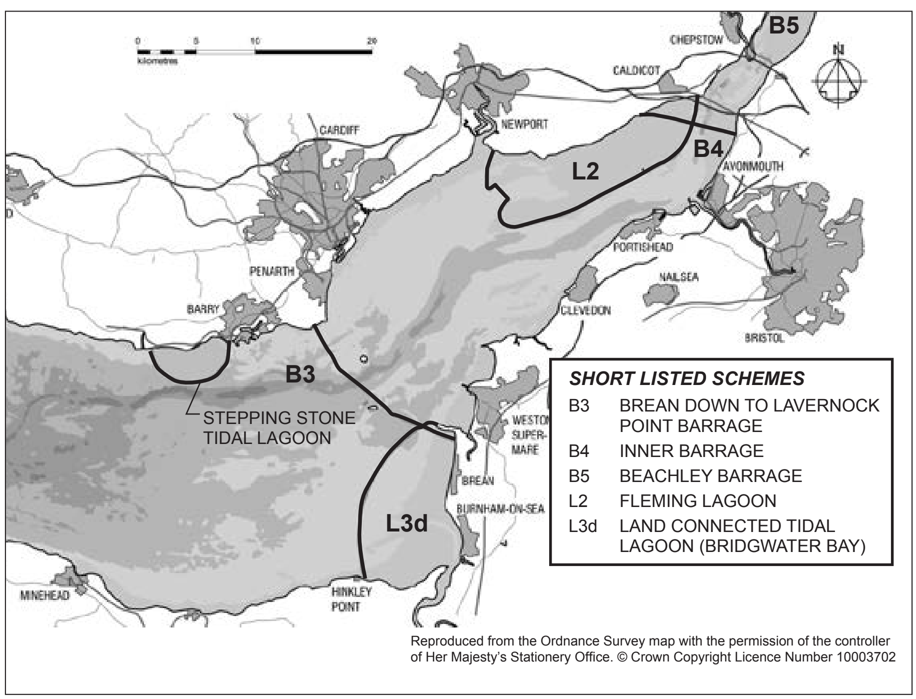


Figure 1 – Plan on the Severn Estuary showing short-listed options in the UK government's feasibility study

[1] http://www.british-hydro.org/downloads/La%20Rance-BHA-Oct%202009.pdf

[2] Parsons Brinckerhoff led the consulting consortium undertaking the Severn Tidal Power Feasibility Study in 2008 – 2010 and also acted as technical advisor for the SETS programme looking at embryonic technologies that could be suitable for deployment in the Severn and elsewhere.

The Canadians (at the Bay of Fundy) and the Russians have built smaller pilot plants, but it wasn't until South Korea moved forward with its 254MW Sihwa[3] plant in the last decade that a recent commercial scale tidal range project has been developed. Tidal range projects have two forms:

1) A tidal barrage that connects two land points on opposite shorelines (see Figure 1 – alignments B3 and B4); and
2) A tidal lagoon that connects two land points on the same shoreline (see Figure 1 – alignments L2 and L3d).

Power can be generated only on the ebb tide or on both ebb and flood tides and can be augmented by adding sluicing and pumping variances to further increase generation heads.

The power generated from a tidal range turbine is calculated in the same way as a hydropower plant with the power produced being directly related to the head of water and the flow through the turbine. The power, at any point in time, is dependent upon the depth/storage relationship of the impounded basin, the difference in level between the impounded basin and the natural tide, the corresponding head and flow, and the efficiency of the turbine at that head and flow. Normally a simple 0-D (flat basin) or 1-D (a long section through the basin) hydrodynamic model is used to take a first estimate of the power yield likely from a site, but as tidal range sites exist in dynamic estuaries where water profiles vary longitudinally and horizontally, accurate estimates require a 2-D hydrodynamic model which simulates the effects on the water profile horizontally and longitudinally. 3-D modelling is now also possible where currents are modelled at different depths rather than averaged. Figure 2 shows how energy generation changes the natural tidal cycle within the impounded basin.

Figure 3 – Aerial view of La Rance Tidal Barrage (photograph reproduced from EDF's July 2011 Press Release celebrating 40 years of operation.)

Such changes in the natural tidal regime require serious consideration and the 2-D and 3-D models are used to assess the environmental and geomorphological effects that will result as a consequence of developing tidal range projects in an estuary. As will be obvious from the above, tidal range feasibility studies can become quite complex with long development cycles. However, intelligently executed tidal range projects can be a sustainable form of predictable low carbon generation with the potential to reduce the cost of electricity over time.

Tidal range turbines are large and have to be housed in even larger concrete structures. A 40MW bulb turbine would typically have a rotor diameter of about 8m, rotating at around 60rpm (revolutions per minute). They also

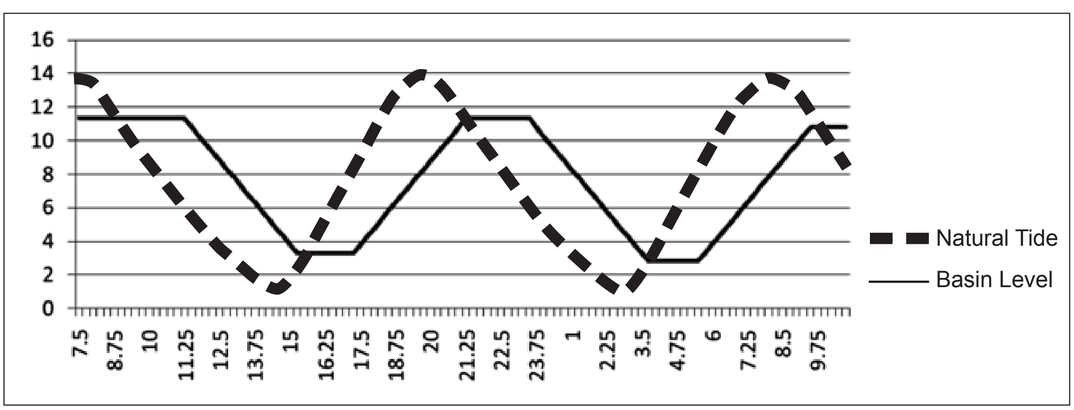


Figure 2 – Variation in natural tide and tidal range power generation water levels on spring tide in ebb and flood operating mode.

[3]http://www.british-hydro.org/uploads/1132008110145AM.pdf

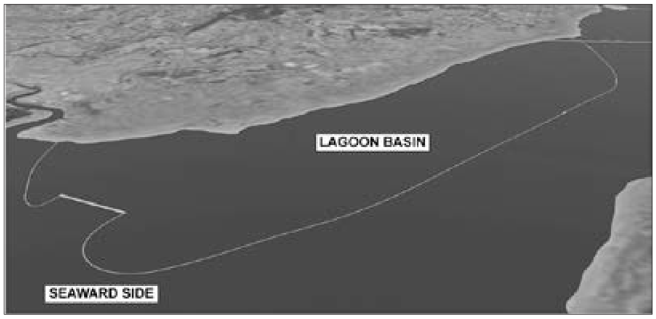


Figure 4 – Computer generated image of a tidal lagoon in the Severn Estuary (source: Parsons Brinckerhoff)

require substantial civil engineering works to form the impounding basin. Figures 3 and 4 show the La Rance tidal barrage and a computer generated image of a tidal lagoon respectively.

Tidal Stream

Tidal stream technologies differ from tidal range in that they exploit the tidal currents rather than the tidal range. They have emerged over the last fifteen years and, in the simplest terms, can be described as an evolution of the wind turbine, adapted to operate in the more challenging environment where the fluid density is an order of magnitude greater, and suitable locations in terms of depth and current are more challenging to find. Tidal currents of 2.5m/s (metres per second) or more are required to generate power efficiently.

Tidal stream turbines have a much lower power density than conventional tidal range turbines and the power calculation is also quite different, being related to the swept area of the turbine blades and the cube of the current flowing through the turbine. As power is proportional to the cube of the current, tidal stream sites require significant currents to generate power economically. The greater the current, the smaller the rotor diameter for a given power output. However, rotors for relatively small tidal stream devices can be 12 to 20m in diameter, rotating at around 15rpm. The largest tidal stream device currently being developed is 1.5MW. This illustrates two of the main engineering challenges with tidal stream turbines—the structural design of large diameter turbine blades and placing of turbines and cables in fast flowing waters.

Tidal stream devices can be deployed singly (e.g., at Strangford Lough[4] in Northern Ireland), in arrays (as proposed for two sites in the UK[5]), or as a fence (as was proposed for the SETS[6] programme in the UK). An array comprises a number of turbines co-located in a grid, whereas a fence comprises a number of turbines set out in a single line across an estuary. A number of the world's largest turbine manufacturers have now entered the tidal stream turbine arena with Siemens having bought Marine Current Turbines (MCT), the technology used at Strangford Lough); Alstoms acquisition of Tidal Generation Limited; and Andritz's Hammerfest Strom turbine. Figure 5 shows Siemen's MCT installation at Strangford Lough.

Tidal Power in Practice

One of the largest tidal ranges in the world occurs in the Severn Estuary bordering South West England and Wales (see Figure 1). At its highest point, near Bristol,

Figure 5 – Cut-away of the Strangford Lough tidal stream turbine (source: Sea Generation Ltd)

[4]hhttp://www.seageneration.co.uk/

[5]http://https://www.gov.uk/government/news/20-million-boost-for-uk-marine-power

[6]http://webarchive.nationalarchives.gov.uk/20110405184751/http://decc.gov.uk/en/content/cms/what_we_do/uk_supply/energy_mix/renewable/severn_tidal_power/embryonic_tech/embryonic_tech.aspx

the tidal range is 14.4m, or over 47ft. Parsons Brinckerhoff has been involved with tidal power projects on the Severn since the 1980s.

In 2006, the government reviewed its energy policy and, with the enactment of climate change legislation that committed the UK to an 80% reduction in carbon emissions by 2050, commissioned new studies on low carbon generation, including tidal power. The initial studies were undertaken by the government's Sustainable Development Commission, which recommended that further, more detailed studies should be undertaken on the Severn. Following an invitation to submit proposals, a consortium led by Parsons Brinckerhoff was appointed to lead the two year study, and a long list of over 10 potential "significant" options were evaluated before reducing this to a shortlist of five, three barrages and two lagoons. "Significant" in this context meant large—typically over 1GW of installed capacity. However, the study concluded that the size of the five feasible options was directly related to the adverse environmental impacts, particularly for the barrages. One of the land-connected lagoons, Bridgwater Bay (L3d in Figure 1), however, came out of the study with some significant benefits in terms of reduced impacts on navigation and with potentially acceptable environmental impacts.

Completion of the study in 2010 encouraged a fresh look at the evidence base that had been created to identify what opportunities should be followed up, if any. The Bridgwater Bay lagoon was an obvious starting point but had a capital cost of over £10bn, not particularly attractive in those days shortly after the credit crunch. The focus changed instead to smaller tidal lagoons, with better ground conditions and more innovative impoundment designs, so that the potential of lagoons could be demonstrated. Parsons Brinckerhoff's concept was that a series of smaller tidal lagoons could form the basis of an incremental approach, whereby the first lagoon is built, and experience gained from the first is then used to build a second, and so on. Parsons Brinckerhoff, assisted by Black & Veatch, worked up a conceptual design for what has been called the Stepping Stones Tidal Lagoon[7] (the semi-circular lagoon in Figure 1). This was, at £1.7bn, capable of being developed by the private sector. It had a rated power output of 600MW and an annual energy yield of 1.2TWh/yr (terawatt-hours per year) with a lower cost of energy than the previously favoured barrage proposals. In addition, tidal lagoons had a bigger advantage, namely, they did not interrupt the main navigation routes and environmental impacts were largely confined to the area within the impounded basin. As such they don't require extensive navigation or environmental mitigation measures.

At the same time, Regen SW[8], the regional energy advisory organisation, along with the newly created South West Marine Energy Park[9] (a government initiative to focus marine energy resources within a geographical region) published a balanced technology approach[10] for the Severn Estuary which promoted the concept that different technologies could be deployed collaboratively with both existing and emerging technologies, at appropriate scale, offering a more sustainable approach than one single mega-project. It was a simple matter to integrate Parsons Brinckerhoff's incremental approach, based on tidal lagoons, with the balanced technology approach and its mix of technologies to produce a single best practice approach, with practical project examples and consideration of how a phased development could use both existing technology today whilst still allowing scope for emerging technologies to be used in the future.

This approach was endorsed by both the UK government and the select committee on energy and climate change when considering whether to support a large tidal barrage proposal from the private sector earlier this year[11]. It has also been endorsed by many environmental and commercial stakeholders as a more sustainable and appropriate approach than a large barrage[12].

No technology has been ruled out on the Severn, including a large barrage; nonetheless, Parsons Brinckerhoff's role in searching for a more sustainable alternative, exemplified by the Stepping Stones Tidal Lagoon, informed by its work on the Severn Tidal Power Feasibility Study and the associated SETS programme, has been helpful in informing stakeholder perspectives. Working with the

[7]http://regensw.s3.amazonaws.com/120831_stepping_stones_tidal_lagoon_presentation_for_bristol_tidal_forum_ead4881f6fce116d.pdf

[8]http://www.regensw.co.uk/

[9]https://www.gov.uk/government/news/south-west-makes-splash-as-first-marine-energy-park

[10]http://regensw.s3.amazonaws.com/bristol_channel_energy_balanced_technology_approach_20121127_c541010d0b3719f8.pdf

[11]http://www.parliament.uk/business/committees/committees-a-z/commons-select/energy-and-climate-change-committee/inquiries/parliament-2010/a-severn-barrage/

[12]http://www.sustainablesevern.co.uk/

South West Marine Energy Park, Parsons Brinckerhoff has also been active in assisting local authorities and stakeholders in planning how energy from the Severn could be successfully developed in an environmentally sustainable and economically beneficial way.

Although the Severn is one of the largest tidal energy resources in the world, there are also many others that are being investigated to see how and when tidal energy may be generated. For such a nascent industry, there are many organisations, large and small and including Parsons Brinckerhoff, taking a keen interest in marine energy in parts of the UK, France, Canada, the US, and Korea, to name but a few. The stakeholder engagement model being used on the Severn to develop a transparent, incremental, and evidence-led approach is very relevant to other potential marine energy development zones around the world. With many countries actively seeking to reduce carbon emissions from their energy use, the coming decades are likely to see a significant increase in the amount of marine energy being used worldwide.

[The author would like to thank the many stakeholders of the South West Marine Energy Park who have worked collaboratively to promote the benefits and challenges of marine energy, as well as those colleagues at Parsons Brinckerhoff who have worked on the various tidal energy studies undertaken in the UK in recent years.]

Peter Kydd *is Parsons Brinckerhoff's Director of Strategic Consulting in the UK and has over 34 years of experience in the energy, transportation, and social infrastructure sectors. He was elected Chair of the South West Marine Energy Park, and led the consortium of consulting firms engaged by the UK government to study options for the Severn Tidal Power Feasibility Study. He has been at the forefront of developing an incremental and sustainable approach to the development of tidal power in the UK.*

The Generation of a Flow Time Series for a Hydropower Plant in Ethiopia with Limited Data

by **Eric CP Lam**, Sydney, AUS, 61-2-9272 5442, elam@pb.com.au

A flow time series is crucial for the estimation of hydropower potential at a site because time series informs the amount of flow available for power generation at different time instances. Energy generated can be calculated at each corresponding time instance by using the available flow volume and hydropower plant characteristics.

As part of a master planning project for the Ethiopia power sector, a time series of inflow to the Abu Samuel hydropower plant near Addis Ababa, Ethiopia was required as one of the forty-plus hydropower plant inflow time series inputs to AQUARIUS (a software system designed to simulate and optimise the operation of water and power supply systems). These inflow time series are extracted from previous studies, design reports, or generated by correlation with flow recorded at nearby gauging stations[1].

Although the design report for the Abu Samuel hydropower plant was available, the report only contained a typical monthly flow pattern for a year and an annual flow duration curve for the plant. There was no time series available and this report is the only source of information available for the Abu Samuel hydropower plant. Flow recorded at the river gauge "closest" to the plant has a flow duration curve quite different from the inflow characteristics described in the design report. This article describes how an approximate flow time series can be generated using only this limited amount of information.

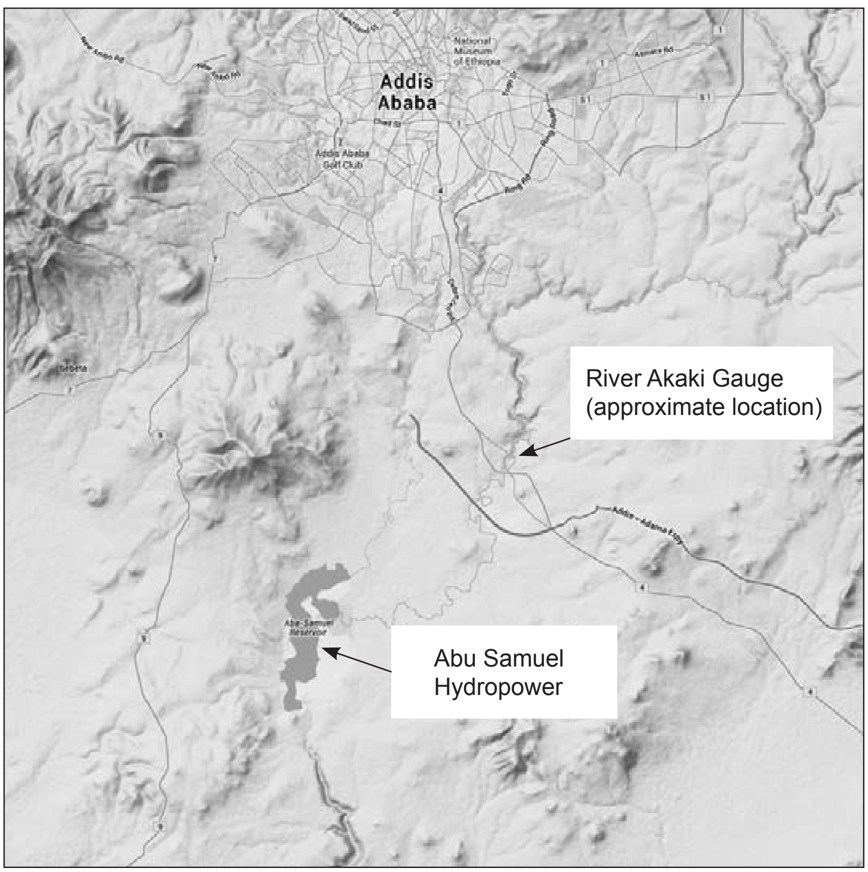


Figure 1 – The Abu Samuel hydropower plant near Addis Ababa, Ethiopia

The Challenge

The flow time series will be used to estimate the amount of energy generated from the Abu Samuel hydropower plant at any particular month between 1961 and 2005 for the purpose of a master planning project for the Ethiopia power sector. While the flow duration curves provided in the design report allow for the estimation of energy that can be generated from the Abu Samuel hydropower plant, it was

[1]Gauging stations are facilities used by hydrologists to automatically or manually monitor streams, wells, lakes, canals, reservoirs and/or other water bodies. Instruments at these stations collect information such as water height, discharge, water chemistry, and water temperature.

not possible to estimate the amount of energy generated in a particular month within the 1961-2005 period. This is important for master planning as, while on the average there could be sufficient energy generated for the power consumption in Ethiopia, there could be time periods when the shortage of power is unacceptable. The relative timing of energy available for consumption from different power plants is important. Thus, a flow time series needs to be generated to satisfy the following characteristics:

- The time series must have a similar annual flow duration curve as the one provided in the design report; and
- The time series must have similar seasonal and annual variations between 1961 and 2005 in relation to the meteorological conditions in Abu Samuel.

Approach to resolve the problem

Since there is no flow time series available at Abu Samuel and information on the catchment characteristics is very limited, approaches available for the generation of a time series are also very limited. To satisfy the above requirements, the following three possible approaches can be taken:

1. Utilize the Akaki River 1981 to 2005 flow time series (the Akaki River has the nearest gauging station with flow records, see Figure 1).
   - A flow duration curve can be developed using 1981-2005 recorded annual flow at Akaki River.
   - The Akaki River flow duration curve and the Abu Samuel flow duration curve are first normalised by dividing with the medium (50 percentile) flow. A correlation is then developed between flows at a range of flow exceedance probability[2] in the two flow duration curves. The best-fitting correlation is found to be a power function with a correlation coefficient (r^2) of 0.99.
   - The power function can be used to transform the Akaki River flow time series to the Abu Samuel time series for annual flow in the 1981 to 2005 period.

2. Utilize the annual rainfall time series in Addis Ababa between 1961 and 1980.
   - Rainfall in the Addis Ababa observatory was obtained for the 1961 to 2005 periods (1986 rainfall data is missing). According to the design report, the Addis Ababa station is the closest meteorology station to Abu Samuel and so the seasonal and annual variation of the Addis Ababa rainfall station should be representative of the seasonal and annual variation of flow in Abu Samuel. Similar to the flow time series for the Akaki River, a normalised rainfall duration curve can be developed and correlated to the Abu Samuel flow duration curve. The best-fitting correlation is found to be a power function with a correlation coefficient (r^2) of 0.98.
   - The Addis Ababa rainfall data can be transformed to the Abu Samuel inflow for the 1961 to 2005 period.

3. Utilize the rainfall runoff model to generate a flow series using Addis Ababa rainfall records.
   - Although there is no flow data for the calibration of the rainfall runoff model, the rainfall runoff model can still be used to generate a flow database on rainfall in Addis Ababa and the catchment characteristics of Abu Samuel.
   - The generated flow time series can be calibrated against the flow duration curve provided in the design report.

The first and second approaches are very similar, while the third approach is more complex and requires collections of more catchment data and setting up of a rainfall runoff model. It is questionable that this third approach will provide a more accurate time series, but it will introduce another layer of uncertainty as the understanding of the Abu Samuel catchment characteristics is limited.

An attempt was made to correlate the Addis Ababa rainfall time series with the Akaki River flow time series, but the correlation was found to be very weak. Also, the design report does not mention the use of the Akaki River flow time series, but Addis Ababa climate conditions are described as most relevant to the Abu Samuel catchment. In addition, the first approach can only generate a flow time series between 1981 and 2005 (see Figure 2) while the flow time series required is between 1961 and 2005. It was therefore decided to adopt the second approach to generate the flow time series for Abu Samuel. Monthly flow was then generated using the typical monthly flow variation in a year provided in the design report.

Figure 3 compares the flow duration curve generated using the above approach to the flow duration presented in the design report. A reasonable match was achieved.

[2]Flow exceedance probability describes the likelihood of a specified flow rate (or volume of water with specified duration) available for the generation of hydroelectric power being exceeded in a given year.

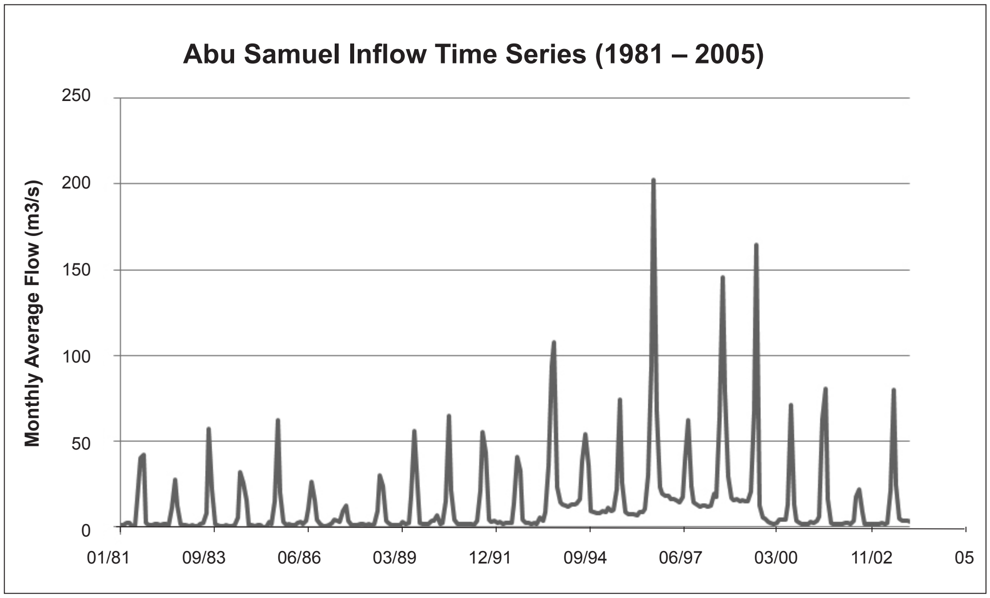


Figure 2 – Monthly average inflow time series at Abu Samuel

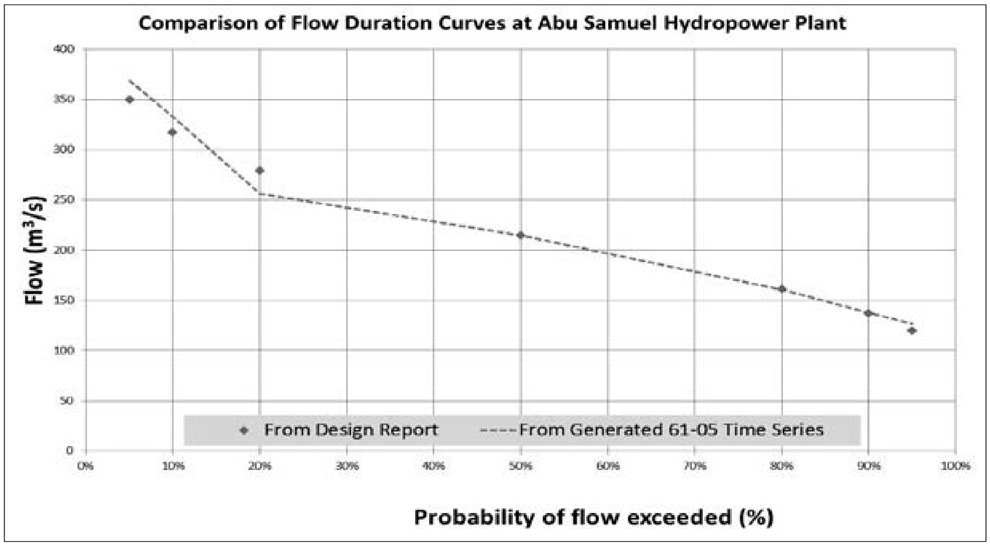


Figure 3 – Comparison of the generated flow duration curve with the flow duration reported in the design report

Conclusion

This article presents an example of how to generate a flow time series with extremely limited available data. Although the generated time series will not be a fully accurate representation of the inflow time series at Abu Samuel, both the estimate of overall generated energy based on this flow time series and the annual and seasonal variations should replicate the actual time series reasonably enough to allow for a master planning study.

__Dr. Eric Lam__ is Principal Hydrologist and a Chartered Civil Engineer with 23 years of experience in the field of hydrology and water engineering in Australia, China, Ethiopia, Hong Kong, India, Lao, Malaysia, Nepal, New Zealand, Philippines, Papua New Guinea, Vietnam, United Kingdom, and Uganda. He is based in Sydney and is experienced in managing a wide range of water engineering projects, including: hydropower schemes; urban drainage/sewerage systems; drainage system for major infrastructures; floodplain management; WSUD; water resource studies; water quality impact assessment; and coastal, lake, and tidal wetland investigations.

Unlocking Value Through a Planning-Led Alliance in Queensland

by **Anthony Domanti**, Brisbane, AUS, +61 7 38546815, domantia@pbworld.com

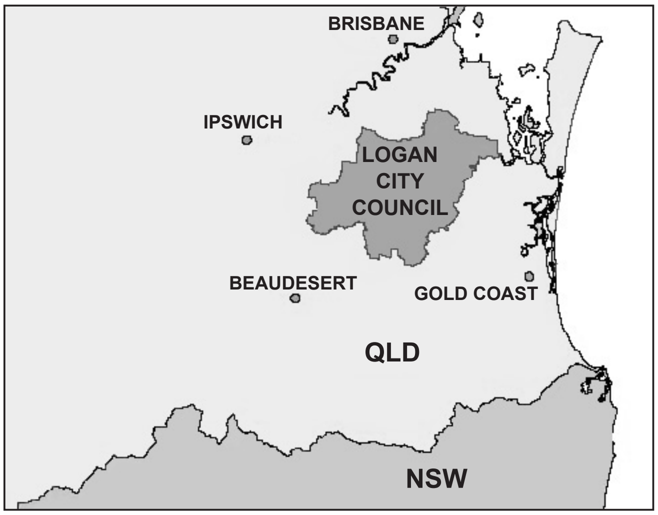


Figure 1 – Locality map

Introduction

Logan City Council's Logan Water Alliance (LWA) is one of the largest water infrastructure delivery programs of its type in Australia. The Alliance is a public and private sector enterprise involving Logan City Council, and engineering services providers Tenix, Parsons Brinckerhoff, and Cardno. The team, consisting of 85 water professionals, was established in August 2009 to meet the demand for water services in Logan City, one of south-east Queensland's fastest growing areas (see Figure 1). The Alliance will deliver new and improved water, wastewater, and recycled-water infrastructure throughout Logan.

The Alliance is known within the water industry for its high-performing team and commitment to deliver *'the right projects for the right costs in the right timeframes'*. This attribute was recognised when the Alliance was awarded the Australian Water Association Queensland Branch's Project Innovation Award in July 2011.

Unlike many alliances, LWA's scope includes planning (master, catchment, and detailed) and design, as well as capital works delivery. This unique 'planning-led' approach allows planning decisions to directly influence the scope and delivery of the Alliance's annual capital works program, and to 'unlock value' during the early stage of its projects, when the potential for value creation is at its greatest. This is the time when the cost of making changes to project parameters, such as location, scope, and timeframe, is relatively small, while the ability to innovate and consider alternative approaches to infrastructure challenges is at its greatest, as illustrated in Figure 2.

This paper focuses on LWA's most notable value-for-money initiative to date — the Alfred Street Pump Station to Loganholme Wastewater Treatment Plant (WWTP) Rising Main project — which clearly demonstrates how value can be created during a project's planning phase.

Discussion

For this project, the Alliance faced the challenge of upgrading the wastewater conveyance system in the Loganholme catchment; the system services a population of approximately 200,000 people. One constraint of the project was that, although the conveyance system needed to terminate

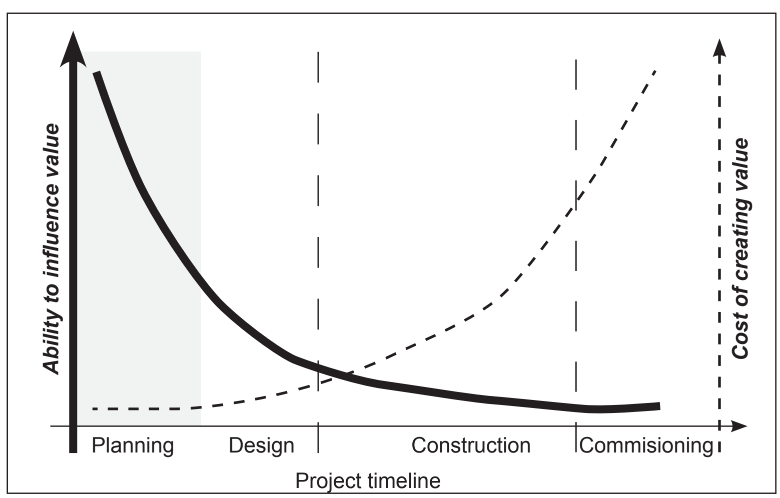


Figure 2 – Value creation diagram

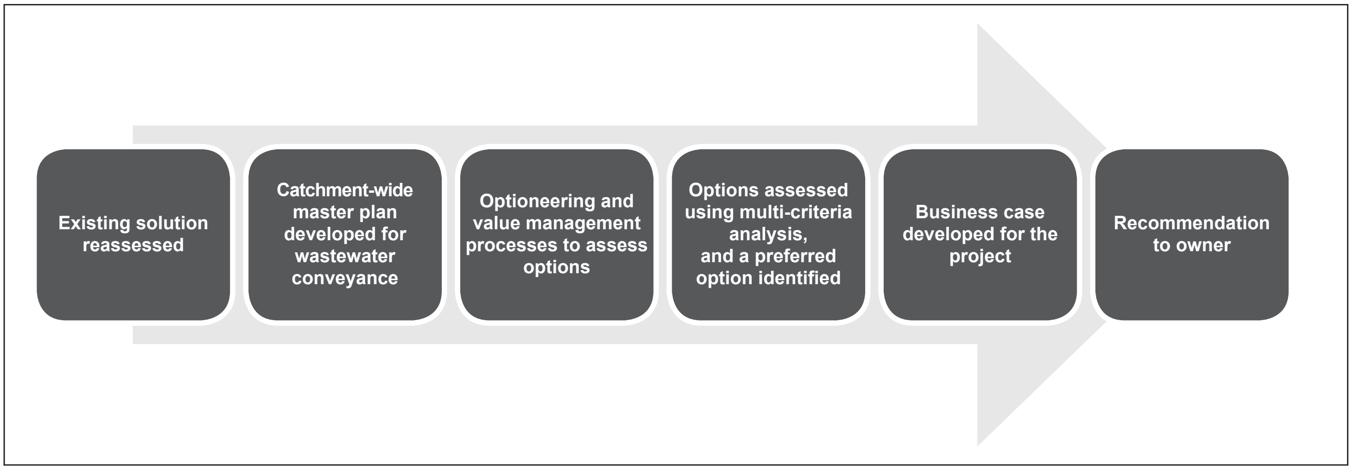


Figure 3 – LWA planning assessment process

at the existing Loganholme WWTP, the inlet works at the WWTP were unable to meet even the current demand. Before the Alliance was formed, Logan City Council had identified a $132m solution for upgrading the conveyance system and Loganholme WWTP inlet works. This solution included duplicating the existing conveyance system and involved:

- 4km of deep wastewater gravity mains (tunnelling up to 19m deep) in a highly developed catchment;
- construction of a 30m lift station at the Loganholme WWTP;
- significant local community disruption (including traffic impacts, construction impacts, business impacts); and
- high energy requirements associated with double lifts of wastewater flows.

Planning review

The Alliance's Planning and Project Development (P&PD) team reviewed the solution, reassessing wastewater collection for the whole of the northern Logan catchment rather than focusing on the insufficient capacity at the Loganholme WWTP lift station. The Alliance developed a new approach to provide adequate long-term capacity between the Alfred Street pump station in Slacks Creek and the Loganholme WWTP. The team also reassessed inputs, such as the area's population trends, to identify several conveyance options. These options were assessed using a multi-criteria analysis, which included assessments of whole-of-life costs and non-cost factors such as environmental, social, and technical impacts. Figure 3 illustrates the planning assessment process adopted by LWA.

The team identified an alternative solution that appeared to offer significant savings in net present cost and annual operating costs. This option along with eight others, including 'non-infrastructure' and 'do nothing' options, were then rigorously tested using an optioneering process and value management workshops attended by LWA and Logan City Council stakeholders. The Alliance's recommended detailed planning solution consisted of a 7km DN1350 shallow rising main, predominately through floodplain and open-space areas. This option would cost $64m. Figure 4 compares the recommended solution with the pre-Alliance solution.

Design phase

During the detailed design phase of the project, the Alliance refined the recommended planning solution represented in Figure 4. The process used to finalise the recommended solution included holding design, opportunity, and risk (DOAR) workshops at the 30% and 85% design intervals. The DOAR workshops were used to systematically review all aspects of the design and capture contributions from a wide variety of stakeholders, including designers, constructors, and operators, as well as community, environmental, and safety specialists. Safety in design, an essential consideration during the life of a project, was also assessed at the DOAR workshops. The following central issues were addressed in the detailed-design phase:

- maximising the use of existing infrastructure; and
- reducing maintenance requirements and improving system longevity.

Maximising the use of existing infrastructure

The Alfred Street pump station is the primary collection system that services the Loganholme wastewater catchment. There are two separate pump stations on the site: the original 'operational' pump station and the newer wet-weather 'bypass' pump station. From the planning phase it was recommended that the bypass pump station be converted to the duty pump station. The bypass pump station is a three-pump submersible type station with an 8.5m dia.

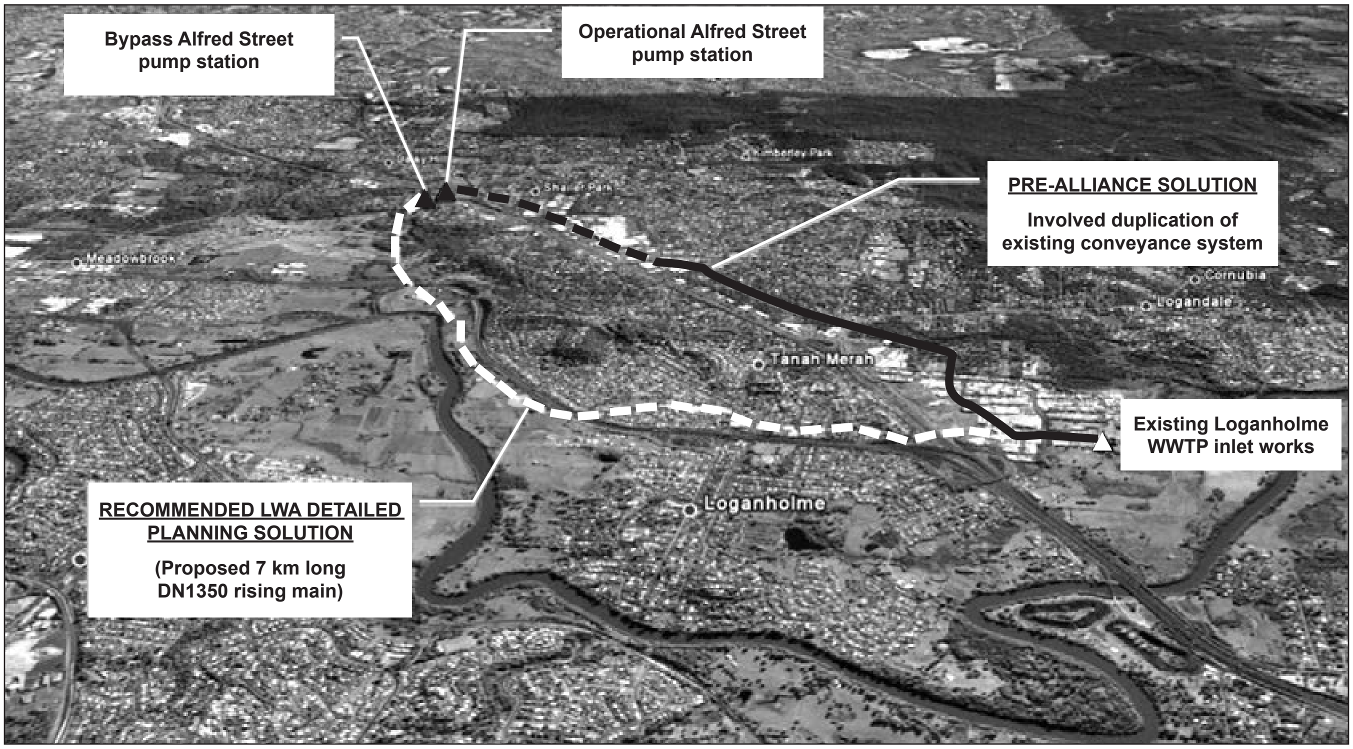
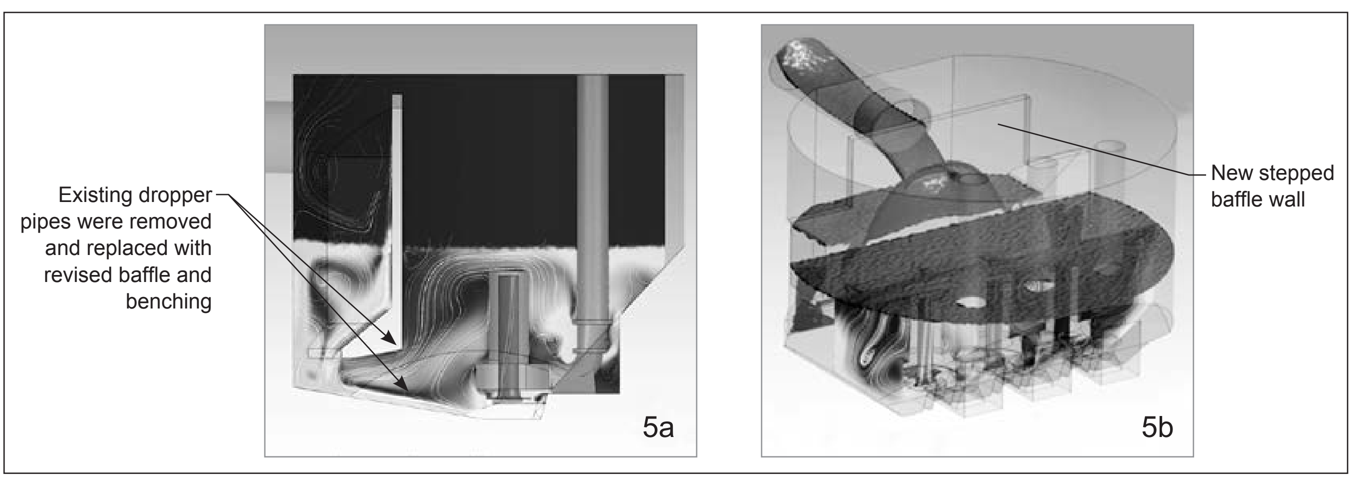


Figure 4 – Comparison of recommended solution (white line) with the pre-Alliance solution (black line)

and an 18m deep wet well, originally designed to deliver 1,300 litres/second (L/s). The Alliance redesigned the bypass pump station using computational fluid dynamics (CFD) modelling to reliably achieve the necessary 2,000 L/s, eliminate some existing problems associated with the pump suction conditions and, ultimately, ensure that a new pump station would not need to be constructed.

CFD modelling of the existing wet well geometry, undertaken by Parsons Brinckerhoff (2011), revealed high swirl angles at the pump inlets for the scenarios with low water levels. Submerged vortices were also detected originating from the side benching. To overcome these hydraulic issues, modifications to the benching and baffle wall were needed. Figures 5a and 5b illustrate the final proposed bypass pump station wet well geometry comprising:

- replacing the existing baffle wall and droppers with a new stepped baffle wall;
- modifying side benching; and
- providing a new flow splitter below the existing pumps.



Figures 5a & 5b – CFD modelling used in the design of the bypass pump station

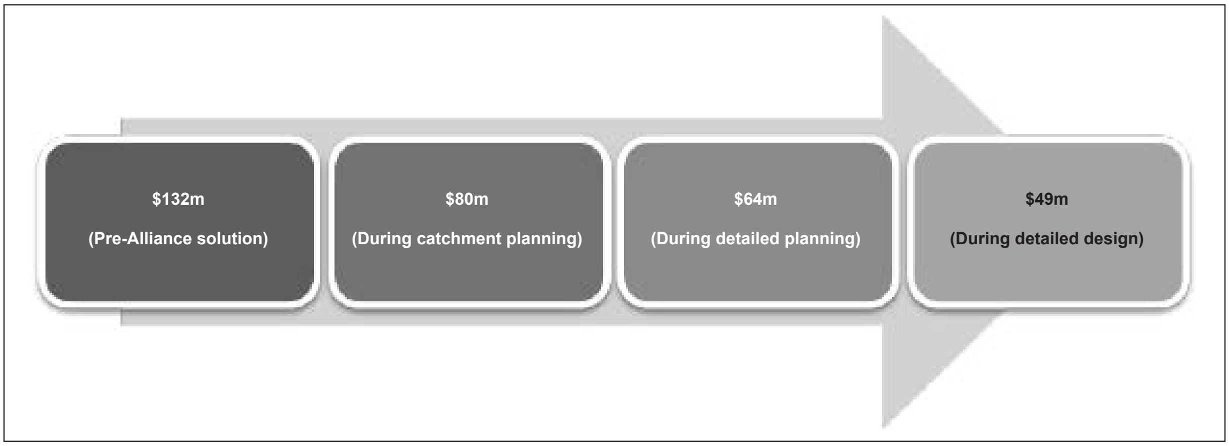


Figure 6 – Progressive value creation through a planning-led approach

Reducing maintenance requirements and improving system longevity

Installing gas-release valves at rising-main high points is common in the water industry; however, if these valves are incorrectly designed, they can lead to community complaints about odour and noise, and require regular maintenance and expenditure. The design approach for managing gas was based on limiting the amount of air being drawn into the rising main (and dissolved gas coming out of solution) under negative transient or static pressures. Large volumes of air drawn into the line become malodourous and are then expelled on pump start, resulting in odour complaints. This was addressed primarily by ensuring the pipeline stayed full during its operation and through minimising the potential for dissolved gas coming out of solution due to a change in pressure.

The issues were overcome by using 'one-way out' and 'low-pressure sealing' gas release valves. In addition, the rising main's vertical profile was designed to ensure that, under static conditions, a minimum of 2–3m head remained in the rising main. This was to ensure that the gas valves sealed (didn't leak sewage) and to reduce the amount of dissolved gas coming out of solution. As added protection for the rising main and to improve system longevity, calcium aluminate cement (CAC) mortar lining was provided at all high points.

Final design

The final design solution includes a 6.4km x DN1200 MSCL/PE rising main that will remove network capacity constraints and remove operational risks associated with a lack of system redundancy. The project's revised capital cost was $49m, which is approximately $83m less than the pre-Alliance solution (see Figure 6).

Figure 7 shows the final rising main alignment and the different construction methodologies to be implemented.

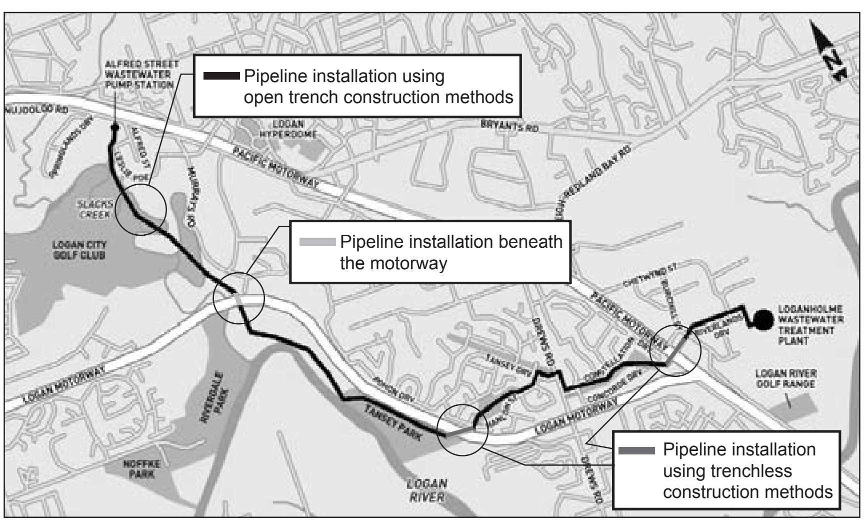


Figure 7 – Alfred Street to Loganholme WWTP rising main: final configuration

Conclusion

The greatest opportunity to unlock value on water and wastewater infrastructure projects is at the early stages of the project life cycle. Logan Water Alliance's planning-led approach has proven to be a successful mechanism for progressively unlocking value and delivering more effective and efficient water and wastewater systems by:

- challenging assumptions during project development to significantly reduce capital and whole-of-life costs;
- significantly reducing operational, environmental, and stakeholder impacts by multidisciplinary input in the early planning phase; and
- using DOAR workshops and robust engineering processes to understand and resolve key stakeholder issues.

The project's numerous benefits include:

- maximising the use of existing infrastructure, particularly at the Alfred Street pump station;
- avoiding construction of new pump stations;
- configuring pump stations to achieve maximum operational flexibility; and
- reducing maintenance requirements and improving system longevity.

The new infrastructure is currently under construction and scheduled for completion by late-2014.

[The author wishes to thank Logan Water Alliance for its input and the opportunity to present this article.]

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Parsons Brinckerhoff. CFD modelling of Alfred Street pumping station (2011)

Anthony Domanti *is a Design Manager in Brisbane and has approximately 18 years of experience in providing services to local government, private developers, and construction contractors in the water supply and sewerage sectors. He led the design on the Alfred Street to Loganholme Wastewater Treatment Plant (WWTP) Rising Main project.*

Regional Water Policy – How to Develop the Best Technical Tools While Working Within a Regulatory Framework

by **Mary Fickert Thomas**, Orlando, FL, US, 1-407-587-7800, thomasmf@pbworld.com; and
David F. MacIntyre, Orlando, FL, US, 1-407-587-7800, macintyre@pbworld.com

Background

Public water suppliers across Florida have historically depended on inexpensive, fresh groundwater from the Floridan aquifer as their primary drinking water source. Five water management districts (WMDs) regulate activities which affect waters of the state and issue water use (or consumptive use) permits to water users. The Central Florida area is divided among three WMDs: the St. Johns River Water Management District (SJRWMD), the South Florida Water Management District (SFWMD), and the Southwest Florida Water Management District (SWFWMD).

In 2006, during a period of very rapid population growth, these three WMDs concluded that the increased use of the desirable groundwater sources would not be sustainable. Therefore, they embarked on a multi-year, multi-phase process to develop alternative water supplies (AWSs) and modify water resource management tools and regulations for the region. Phase I of the process concluded in 2006 with a set of interim water use regulations which limited all groundwater withdrawals in an area known as the "Central Florida Coordination Area" (CFCA) to projected 2013 demands, and required AWS for future needs. Figure 1 shows the CFCA.

Phase II of the process began in 2009 with an objective of establishing a long-term plan for water resources management in Central Florida, and to replace the Phase I interim rules. The work plan included the use of groundwater flow models to predict future groundwater levels in the aquifer, environmental assessments to measure wetland health (a primary constraint on acceptable potentiometric conditions), an assessment to identify where groundwater would or would not be available in the CFCA, public participation to obtain input on new water rules, long-term rulemaking to develop a new set of water rules, and the development of water supply plans which express the results of the process.

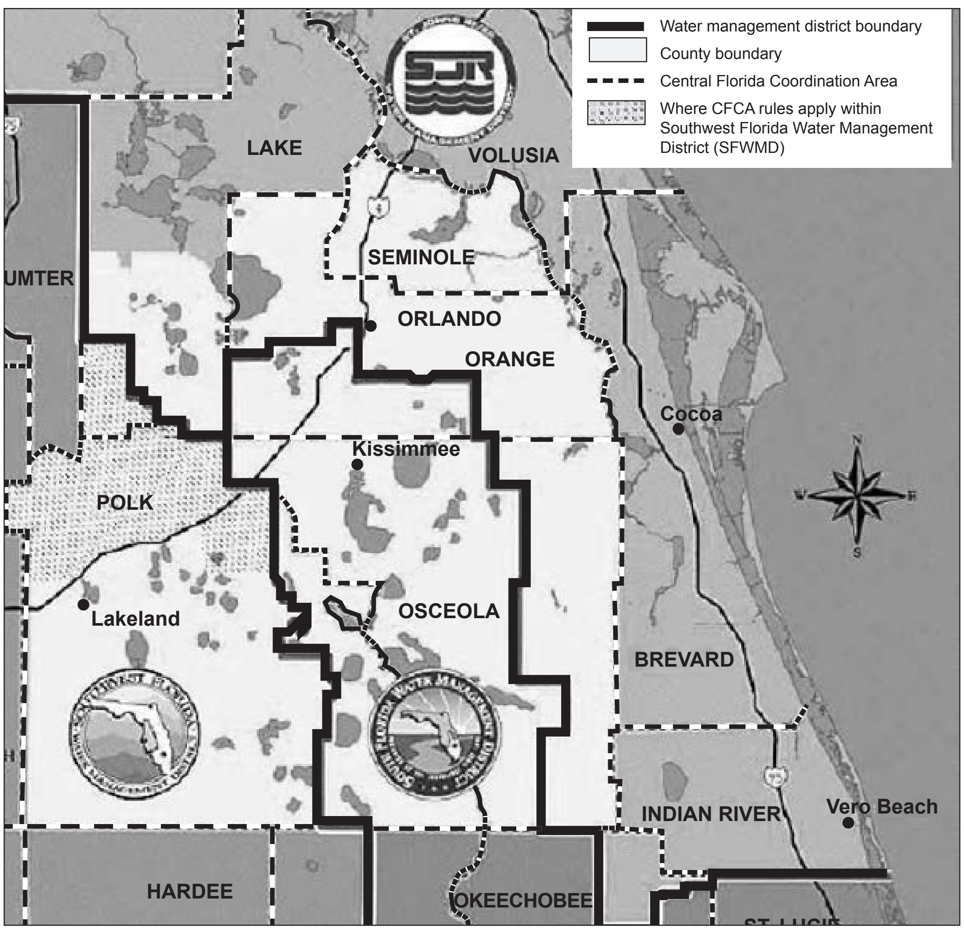


Figure 1 – Central Florida Coordination Area

In 2010, the Phase II WMD-led CFCA public participation process was underway and included routine meetings to inform the public of the progress made to develop new water resource management tools. Meetings summarized progress, but seldom revealed details of the technical products under development. Regional water supply providers (Utilities) therefore requested that the WMDs accommodate a higher level of tool development review and even offered the services of their own consultants so that local-level utility details could be incorporated in the tools. WMD executive directors agreed, and in 2011 the collaborative process now known as the "Central Florida Water Initiative," or "CFWI" was formed. Several of the region's largest utilities retained Parsons Brinckerhoff to lead the technical review and utility participation in the process.

Technical Tools

Overview

There is currently no planning or permitting tool that uses a fully-integrated model for surface water/groundwater interactions in Central Florida, so WMDs use groundwater flow models calibrated with empirical data to evaluate behavior in the groundwater aquifer systems and generally use field-collected data to evaluate the condition of regional lakes and wetlands. As part of the CFWI process, the collaborators (WMDs, public water supply providers, and Florida Department of Agriculture and Community Services) set out to develop metrics by which the WMDs and public alike could better estimate the level of interaction between groundwater and surface water systems.

Groundwater Modeling

WMDs have historically used their own separate models to predict and evaluate the behavior of groundwater aquifer systems. While the models overlap, none cover the entire CFCA and the models differ greatly in some instances where overlap occurs. Where those discrepancies exist, water suppliers find it difficult to predict the amount of groundwater available to serve the citizens of Central Florida. Recognizing a need to develop a tool that would result in a more consistent current and future estimate of groundwater availability across the region, the collaborators supported the development of a regional groundwater flow model to represent the entire CFWI.

Much of the model was developed by the United States Geological Survey (USGS) before the participation of other stakeholders in the CFWI process, and therefore the model did not capture some local level details. Parsons Brinckerhoff, lead consultant for the water utilities that are participating in the CFWI, worked as part of the modeling team to address a number of challenges faced with using a model that was not perfectly suited for its purpose. Parsons Brinckerhoff's contribution to the process included a number of improvements to the model, namely, guidance on recalibration of the model to reflect some changes in the flow records of the Utilities' wellfields and aquifer recharge facilities, and a suggestion to modify the boundary conditions at the edge of the model from annual average values to monthly values consistent with the model's monthly stress periods. These contributions significantly improved the accuracy of the model.

Environmental Assessments

The USGS's East Central Florida Transient (ECFT) groundwater model predicts the behavior of the surficial, Upper Floridan, and Lower Floridan aquifer systems based on factors such as rainfall and groundwater recharge or pumpage. But the current and future ecological conditions of wetlands and lakes in the region and their responses to hydrologic change are critical to the determination of a sustainable groundwater supply for the region. In addition, a more quantitative and repeatable approach to assessing wetland conditions was needed to improve the water supply planning and permitting processes. Therefore, a metric was required to predict the likelihood that a given wetland would be stressed or unstressed, and that metric needed to be tied directly to hydrology.

The first step in formulating a metric that tied environmental stress indicators to hydrology was to identify a dataset of existing wetlands or lakes with long-term hydrologic data. For each of these sites, qualitative condition assessments were conducted. Unfortunately, due to the limited amount of sites with a long period of record, only 46 sites were ultimately selected for this effort.

An adequate metric for wetland stress must contain a hydrologic indicator so that the metric can be both repeated and related to a groundwater flow model. Parsons Brinckerhoff developed a "predictor" tool using data from the set of 46 sites with real data which can be extrapolated to the groundwater flow model. The probability of stress occurrence due to water level change was assessed for each wetland based on its specific initial condition. For wetlands where the initial hydrologic condition is not known, it is still possible to calculate a population-weighted risk level. While this number is not a very accurate indicator for a specific wetland, it is expected to be a reasonably accurate indicator of the total number of stressed wetland systems in each physiographic province that are likely to result from any pattern of imposed water level changes.

Collaboration

The new CFWI process is consensus-based. An executive-level steering committee (SC), management oversight and technical oversight committees (MOC and TOC), and six technical teams were formed. Teams are composed of representatives from each of the three WMDs, a representative from the Florida Department of Environmental Protection (FDEP), a representative from the Florida Department of Agriculture and Community Services (FDACS), and a representative from Utilities. Each of the six technical teams would address the specific technical components that contribute to the region's water resource development and management, while the other teams were formed to guide the process and provide oversight (Figure 2).

Because WMDs are public agencies, the process is subject to Florida's Sunshine Law structure, which requires that policy-making meetings be open to the public and reasonable notice of such meetings be given so that all stakeholders have an opportunity for input. Added to that fact, the WMDs are now combining their scientific resources, expertise, and opinions with those of additional stakeholders, and so there is the potential for lengthy—and sometimes heated—discussions.

To foster technical consensus, technical teams adopted frequent, usually bi-weekly, meeting schedules in which core team members make consensus-based recommendations on all aspects of the tools developed by their teams. The core members nominated two team chairs, one from a WMD and one from Utilities, to keep the meetings on task. Though anyone is permitted to attend meetings and offer ideas, it is only the core group members who are involved in final recommendations. Ultimate recommendations are overseen by two team chairs who sometimes have opposing interests, so acceptable compromises are found when consensus cannot be achieved. Meetings which began as both quite large and lengthy became more organized, more constructive, and even harmonious.

Though rare, when the technical teams cannot reach consensus on a particular technical decision, the issues are raised to the TOC during monthly meetings. When policy issues are at play, the MOC will step in to provide a recommendation during monthly meetings. By allowing the TOC and MOC to stay abreast of the technical team progress, technical issues are often resolved, or at least streamlined, before publicly-noticed steering committee meetings.

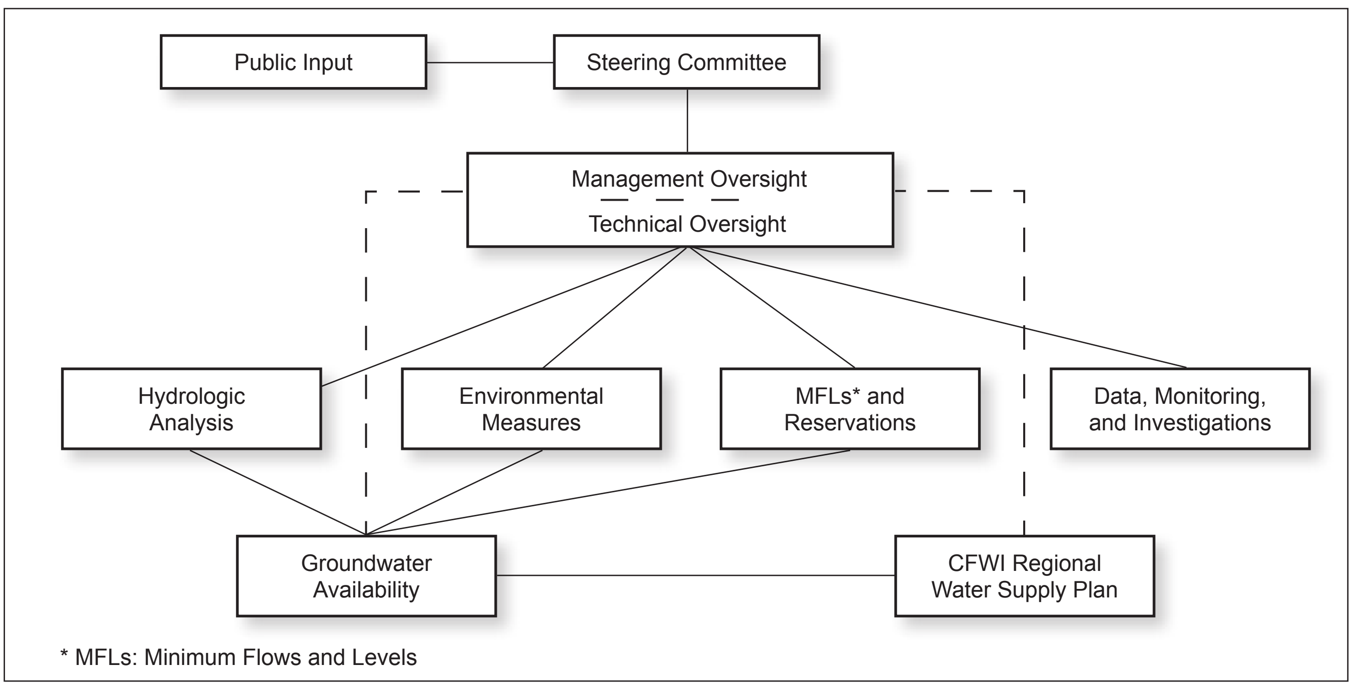


Figure 2 – CFWI Team Structure

Conclusions

A number of challenges were encountered in constructing the CFWI process, a collaborative multi-agency technical process that was efficient yet compliant with Florida's open government Sunshine Law. The technical teams have made great efforts to ensure that the tools used in the process incorporate the best available information, provide an effective level of technical rigor, and are able to be applied by a broad range of practitioners. By developing methods to quantify the interaction between groundwater and surface water systems using regionally consistent approaches, both the WMDs and the public can plan for and permit water use in a way that is transparent, consistent, and equitable.

Perhaps the greatest achievement has been the development of a process in which multiple regulatory agencies and the parties they regulate have collaborated to develop viable solutions to problems of resource allocation and environmental protection.

Mary Fickert Thomas *is a Lead Engineer in Parsons Brinckerhoff's Orlando, Florida office. She is the Project Manager of a number of regional projects, including the development of a regional monitoring program for five different utilities, and the CFWI project.*

David MacIntyre *is a Water Resources Engineer with a broad-based background in hydrology, contaminant transport, hydrogeology, and computer modeling of groundwater and surface water systems. He is Senior Technical Specialist in desalination, reuse of reclaimed water, hydrogeology, groundwater modeling, aquifer management, and assessment of groundwater/surface water interactions.*

Using GIS to Support Adelaide's Water Security

by **Matt Brown**, Adelaide, AUS, +61 8 8405 4423, BrownMa2@pbworld.com

Project overview

The $403m North South Interconnection System Project (NSISP) is a crucial component of the government of South Australia and SA Water's Network Water Security Program, a long-term strategy to deliver a flexible, integrated solution for water transfer and distribution in Adelaide through 2050 and beyond. The project connects and upgrades metropolitan Adelaide's northern and southern water supply sources, linking them to provide a single city-wide network to meet Adelaide's immediate and future water needs. This has given SA Water the flexibility it needs to use its water resources efficiently and has increased the community's security of water supply. The NSISP has involved the construction of four new major pipelines totalling 32km in length, three new pump stations, and a series of other works throughout the metropolitan network.

Parsons Brinckerhoff partnered with MWH and Tonkin Consulting to form the WaterLink Joint Venture, which was responsible for the concept development, detailed design, and provision of engineering and project support services. One part of Parsons Brinckerhoff's involvement on the project was managing the geographical information systems (GIS) component. GIS is a system that is designed to capture, store, digitalise, analyse, manage, and present all types of geographically referenced data. The system used on NSISP was customised to cover the extent of over 120 project sites across metropolitan Adelaide.

The NSISP is a good example of the role GIS can play in a major infrastructure project. Like many transportation and utilities projects, water projects often involve linear alignments over a series of alternatives of long corridors, which lend themselves well to geospatial analysis. Geospatial tools (a technological approach for acquiring and managing geographic data using GIS) were shown to be a valuable data-sharing medium among client, consultants, and contractors. Most importantly, GIS supported the project decision-making process to enable SA Water to achieve an efficient, accurate, and cost-effective outcome.

GIS makes a complex project, simple

Access to spatial data became difficult during early design and construction because many team members worked on-site or in external offices. Parsons Brinckerhoff used geospatial tools to create a mapping solution that combined a diversity of data sources into a single location and spatially linked a large quantity of non-spatial information.

All project teams adopted the mapping solution to ensure up-to-date information was used in decision-making. As the project evolved, training tools and resources were created to maximise GIS usage and consistency across each team. All team members were then able to contribute to the GIS database and understand first-hand the benefits of GIS.

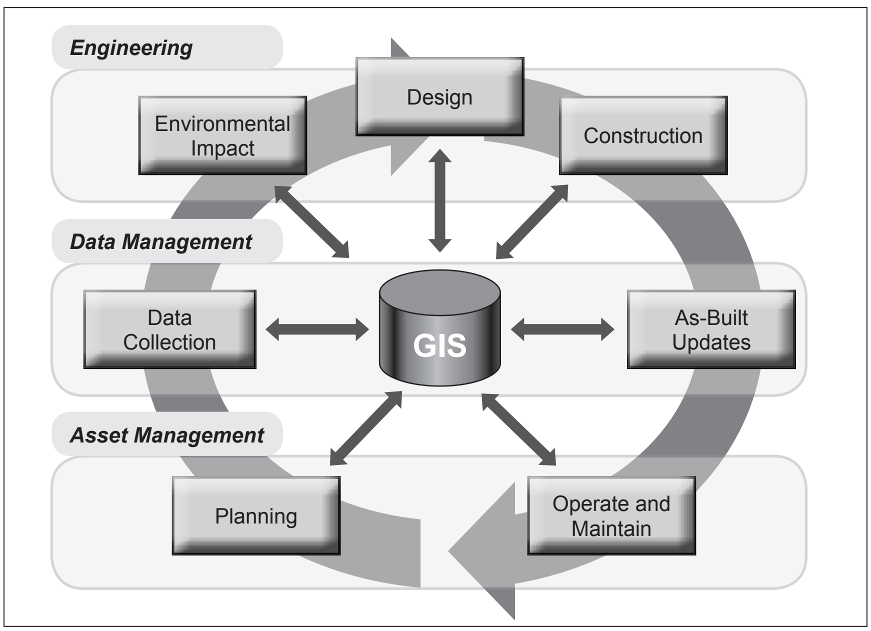
During the project, over 2,500 GIS maps were created to meet the project team's requirements. Parsons Brinckerhoff's mapping solution was used to produce draft maps for collection and collation of field data in preparation for the production of the final GIS maps. This proved to be a fast, efficient, and accurate process.

Early, effective data management through the GIS mapping solution contributed to time and cost savings. It enabled analysis of alternative solutions and incorporated all facets of available data including photographs, drawings, survey data, and field notes across 120 project sites. This easy-to-use resource encouraged individual teams to provide and maintain data from a wide range of sources and allowed the management team to monitor site progress and make informed decisions from the office. This tool assisted in the management and documentation of construction activities and contributed to budget and schedule savings through efficiency gains.

Innovative mapping approach

The mapping solution was initially designed as an internal ArcGIS ArcReader data viewer, a software mapping application. This ArcReader viewer allowed quick updates in the GIS database and was easy to manage and control; also, it didn't require an internet connection. However, users of the ArcReader viewer needed to have the software installed and access to the network.

As the project team grew, the ArcReader viewer was no longer suitable. Access to spatial data became difficult during detailed design and construction because many team members worked on-site or in external site offices. At the end of 2011, Parsons Brinckerhoff upgraded the ArcReader viewer to an external web-based application using ArcGIS ArcServer and Silverlight. The enhanced access meant that anyone on the project team with an internet connection could access the spatial data at any time and from anywhere.



This innovative approach and web-based technology access was a first for SA Water on a large infrastructure project. Secured by a user log-in and password, the external site was easy to use and navigate. Nightly database updates provided the latest information. Team members in the project office and in site offices used the application for a range of activities including to keep track of site construction progress, and to complete safety and construction audits and progress claims.

During the design and construction phases, photos collected from eleven GPS cameras and nine smart phones were an important resource for this tool. Photos uploaded to the site were linked and displayed using GPS attribute data. At the end of construction, the GIS system contained over 42,000 photos.

Conclusion

Geospatial tools are in use for many of Parsons Brinckerhoff's water, power, transportation, and other linear infrastructure projects. Web-based data viewers help to expand the capability of the tools to serve a larger project team from various sites and organisations, improving collaboration, accuracy, and quality. This GIS approach contributed to the success of NSISP. GIS saved the project time by providing quick access to datasets, analysis tools, and mapping information for the project team.

The NSISP has achieved every major milestone and target. Operational handover commenced on time and within budget at the end of 2012, 18 months ahead of the original program. The customised GIS application tools supported this outcome. The benefits of GIS and the contribution to the NSISP have been acknowledged when the project won the 2011 South Australian Spatial Excellence Award in Infrastructure and Construction and was a finalist in the 2011 Asia Pacific Spatial Excellence Awards.

Related website

http://www.sawater.com.au/SAWater/WhatsNew/MajorProjects/NSISP/NSISP.htm

Matt Brown *is a GIS Consultant in Parsons Brinckerhoff's Adelaide office and worked on the North South Interconnection System Project from 2010–2013.*

Overcoming Design-Build Project Deliverable Challenges

by **Colin Haggerty**, Denver, CO, US, 1-303-390-5844, haggerty@pbworld.com; and
Robert Welch, Los Angeles, CA, US, 1-213-362-9470, welchrc@pbworld.com

The Colorado Department of Transportation (CDOT) Interstate 25 (I-25) Design-Build Project involved the expansion of I-25 from the north side of Colorado Springs to the town of Monument. The 11 mile, $55 million expansion included the addition of two travel lanes along the corridor as well as the reconstruction and rehabilitation of two bridges, seven major box culverts, and numerous minor stormwater crossing culverts. Reconstruction of this section of roadway required implementation of stormwater quality improvements for all of the new and existing impervious surfaces, and detention facilities for the new additional impervious surfaces. Erosive soils in the project area necessitated restoration of stream reaches and installation of unique energy dissipation at culvert outlets.

The design-build project was awarded to the client (contractor) who proposed to shorten the timeline by nearly one year and to deliver the completed project with full traffic capacity by December 2013. As part of the design-build team, Parsons Brinckerhoff completed the roadway design, structural design, environmental permitting process, and hydraulic and water quality design. Overall design began in February 2013, two months after the proposed start date of December 2012 due to additional time required for the procurement process. However, in order to meet the accelerated construction timeline, the design completion date remained in June 2013. Working together with multiple disciplines presented several challenges as well as new opportunities for team building.

One of the biggest challenges of the project was the hydraulic and stormwater quality treatment design. The request for proposal (RFP) required the hydraulic and water quality treatment design to follow design standards per the CDOT Drainage Design Manual (DDM). However, the contract documents limited the design options to surface extended detention basins for all detention and water quality treatment features, as well as proprietary water quality vaults in locations where only water quality treatment is required. Early in the coordination process, the project team identified problems with limiting the treatment techniques; however, the owner (CDOT) requested that the design team proceed with the design as specified in the contract documents. After the first design submittal package, the constructability and high cost concerns were clearly exposed. A halt was placed on the water quality treatment design while alternative concepts were developed and reviewed.

Alternative Hydraulic and Water Quality Treatment

Early in the design and procurement phase, Parsons Brinckerhoff identified opportunities for alternative treatment techniques for providing water quality and detention. During the water quality treatment design halt, these alternatives were reevaluated by the stakeholders and discussions restarted to solve the project requirements. Opportunities for banking[1] or equivalent benefit areas were reviewed to meet both project requirements —stormwater quality treatment and stormwater detention facilities. Guidance on water quality banking is only briefly described in CDOT's Municipal Separate Storm Sewer (MS4) permit, and consensus between the client and owner on using this design alternative could not be achieved. It was decided that water quality treatment would be required and constructed along the entire project area adjacent to the roadway in lieu of banking. Banking of detention requirements is more commonly performed and therefore it was proposed that detention facilities be placed at multiple locations both onsite and offsite.

[1]Water quality and detention banking take advantage of offsite areas that drain toward the project. By treating these offsite areas, equivalent impervious on-site areas can be freely discharged.

Water Quality Treatment

Although water quality treatment was required within the project area, it was clear that the techniques proposed in the RFP would not be feasible for much of the project. Similar to many other jurisdictions, the CDOT MS4 permit requires either 100% capture of the water quality capture volume (WQCV) or removal of 80% of total suspended solids (TSS). Alternative techniques such as media filters (used frequently in the state of Washington) and grass filters were investigated to determine their effectiveness and applicability to the project. Due to the arid climate of the Front Range of Colorado, filtering techniques that rely on vegetation were ruled out as the primary water quality treatment.

After numerous discussions with CDOT, it was determined that nearby projects would utilize grass-lined ditches with rock check dams to provide water quality treatment (see Figure 1). These facilities had been used on smaller scale projects and therefore CDOT requested that Parsons Brinckerhoff devise a technique to quantify the actual treatment provided. To meet this requirement, Parsons Brinckerhoff looked at an average width of roadway and determined the quantity of runoff generated during a ‘water quality storm event’. A water quality storm event along the Front Range is generally considered an event that generates 0.5” of runoff depth from an impervious surface (CDOT). Calculations concluded that a roadway 60 feet in width results in a volume of 2.5 cubic feet of WQCV per linear foot of roadway.

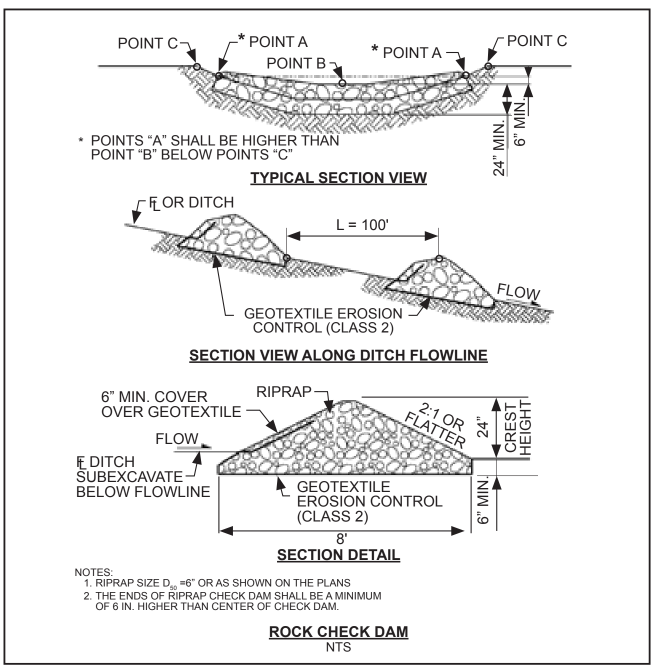


Figure 1 – Grass swales with rock check dams for infiltration of water quality storm events

Appropriate storage was then provided in the grass-lined swale with rock check dams. The storage volume was estimated by a combined function of the height of the check dam and the slope of the ditch. The standard ditch geometry used for the project is a V-shaped ditch with 3:1 side slopes. Utilizing this geometry and a check dam height of 2-ft, the volume detained at each check dam was calculated based on the equation of a tetrahedron, which is 1/3 the area of the base (the face of the check dam) times the height (the length of ditch based on the slope to obtain 2-ft depth). By varying the spacing of the check dams between 100 and 500 feet, the volume required for treatment was provided within the grass swales with rock check dams.

To provide debris settling time, a minimum of 12 hours of retention time is a generally accepted residence time. Type A and B soils[2] within the project area yield an infiltration rate of 1” per hr over the extent of a water quality storm event (Urban Drainage and Flood Control District, BMP Calculator).

Once the treatment was quantified, the task of coordinating the ditch layout with the roadway grading team began. The contractor required a single surface to be the final product and therefore the ditch layout and grading needed to be incorporated into the overall surface. Working closely with the civil design team required an iterative effort to assure the proper size and slope was achieved. Preliminary layouts for the ditches were set by the water group for the roadway group to incorporate into the grading. Once the initial grading was completed, the layout, slope, and sizing were reviewed and changes incorporated. After the second grading run, the spacing of the rock check dams was determined. Breaks in slope were analyzed separately to optimize the check dam spacing.

[2]The US Department of Agriculture National Resource Conservation Service (NRCS): Type A – Soils having a high infiltration rate (low runoff potential) when thoroughly wet. These consist mainly of deep, well drained to excessively drained sands or gravelly sands. These soils have a high rate of water transmission/sf; Type B – Soils having a moderate infiltration rate when thoroughly wet. These consist chiefly of moderately deep or deep, moderately well drained or well drained soils that have moderately fine texture to moderately coarse texture. These soils have a moderate rate of water transmission

Stormwater Detention

Having the water quality treatment concept finalized, Parsons Brinckerhoff investigated how to provide the required detention. In the area of the US Air Force Academy (AFA), I-25 falls within an easement as opposed to right-of-way[3]. The easement width was actually smaller than originally expected because it did not extend to the fence lines, which were assumed to be the easement limits during the proposal phase. As part of the project requirements, new pavement areas constructed as part of the project within the easement were required to be treated for full spectrum detention (FSD).

FSD is a method of reducing urbanized peak flows for smaller storm events to more closely replicate the runoff peaks before urbanization occurred. The concept captures a volume of runoff defined as the excess urban runoff volume (EURV) and then releases it over 40 to 72 hours of duration. The provision of FSD benefits the receiving waters by replicating historic flows. This will help reproduce channel forming flows that more closely represent predevelopment conditions. In order to provide FSD at offsite, centralized locations, it was essential to establish consensus from the entities involved (CDOT, AFA, and the city of Colorado Springs). All agreed that providing FSD at centralized areas would benefit the receiving waters more than multiple smaller detention basins adjacent to the roadway. Once this consensus was achieved, design of the off-site FSD was coordinated with all of the entities.

Energy Dissipators

In addition to the water quality and detention requirements of the project, the erosive soils in the project area necessitated restoration of stream reaches and energy dissipation at culvert outlets. The majority of cross culverts required standard riprap aprons[4], but three locations required additional analysis. The limited space at Teachout Creek and Monument Branch resulted in modified Colorado State University (CSU) basins being selected to reduce velocities, while a riprap stilling basin was sufficient at Black Forest Creek. The modified CSU basins were selected to provide an aesthetic feature that sufficiently dissipates stormwater energy (see Figure 2). Utilizing boulders as the roughness elements help the features blend into and enhance the environment. Careful consideration of the boulder size and placement relationships between the apron and roughness elements allows for easy construction within a relatively small footprint. A previous discussion with one of the authors of HEC-14[5], Roger Kilgore, assured the team that the extrapolations of the data required for boulder relationships were acceptable and correct.

Once these dissipaters were designed, it was again essential to incorporate the grading necessary for the structure into the overall grading of the project. Working closely with the civil design group, conceptual designs were quickly transformed into digital models that were incorporated into the overall surfaces. Fine grading work was accomplished through design details to assure the design was reflected in construction. By providing unique design solutions for multiple project challenges, the Hydraulic and Water Quality Design Team overcame significant obstacles encountered during design, benefitting the contractor, owner, and ancillary entities, and resulting in a project that was fast-paced, but rewarding for everyone involved.

Figure 2 – Modified CSU basins provide an aesthetic feature that dissipates stormwater energy.

***Colin Haggerty**, PE, CFM has over 10 years of experience in hydrologic and hydraulic engineering and design, which includes work on the I-25 North of Colorado Springs Design Build Project.*

***Robert Welch**, PE, CFM, is a Supervising Engineer in Los Angeles and part of the West Region water group. He has over 12 years of experience in flood control/drainage design.*

[3]The US Air Force Academy owns the property through which I-25 runs. As opposed to many roads, which own their right-of-way, I-25 is within an easement, meaning it is owned by the federal government and not CDOT.

[4]A commonly used device for outlet protection constructed at a zero grade for a distance that is related to the outlet pipe diameter.

[5]US DOT, FHA, Hydraulic Engineering Circulars No. 14, Hydraulic Design of Energy Dissipators for Culverts and Channels

Design to Improve Communities, One Water Quality Retrofit at a Time

by **Kelly E. Lennon**, Baltimore, MD, US, 1-410-385-4162, lennonk@pbworld.com; **Chin Y. Lien**, Baltimore, MD, US, 1-410-727-5050, lienc@pbworld.com; and **Elizabeth T. Kanner**, elizabethk@coastal-resources.net

Introduction

The US was made aware of the potential impact of stormwater runoff to the natural and built environment in 1987 when the US Environmental Protection Agency (EPA) brought stormwater pollution control issues under the purview of the Clean Water Act (CWA) via the National Pollution Discharge Elimination System (NPDES) program. Stormwater runoff is generated when precipitation from rain and snowmelt events flows over the land or impervious surfaces (paved streets, parking lots, building rooftops, etc.). It accumulates chemicals, sediment, trash, debris, and other pollutants that could adversely affect water quality if the runoff is discharged untreated. Urban stormwater discharges via municipal storm drainage systems are considered point sources and require coverage under a NPDES permit. The primary method to control stormwater discharge is the use of best management practices (BMPs).

Today, most communities have stormwater management (SWM) regulations in place to control post-construction stormwater runoff and to protect waterways from continued deterioration of water quality. This was not the case prior to 1987, and SWM requirements before that time were most likely for flood control purposes only. A majority of the nation's urban developments were built without any stormwater treatment systems and so, to achieve the CWA's ultimate goal – restore physical, chemical, and biological integrity of our nation's waterways – there is a need to go back to existing communities and developments and implement stormwater retrofitting.

Benefits of Stormwater Retrofits to Communities

Stormwater retrofitting for existing communities and developments not only improves the water quality of the receiving waterways, but also provides benefits to the overall quality of life.

With better understanding of stormwater issues, BMP facilities and control devices have evolved greatly over the past two decades with continued development of innovative pollution control technologies and techniques.

Dry detention ponds have been replaced by extended-detention or wet ponds, where the stormwater treatment is accomplished through hydraulic means and also through extensive use of emergent or submergent vegetation within the saturated portion of the ponds.

In urban areas, underground structural SWM devices are being replaced by tree-box filters, and large centralized ponds by the installation of green infrastructure (GI) or low impact development (LID) techniques such as green roofs, rain gardens or bioretention cells, bioswales, and infiltration basins. Green infrastructure is being promoted as a sustainable way to implement SWM retrofit/enhancement. Green infrastructure (such as trees, green roofs, and bioretention areas) creates shade, reduces the amount of heat absorbing materials, and emits water vapor – all of which cool hot air and reduce the urban heat island (UHI) effect. Additional vegetated areas can reduce ground level ozone (smog) by reducing air temperatures, reducing emissions associated with air conditioning, and removing air pollutants.

As a result, communities are experiencing more street trees, more green space, cleaner air, and a more aesthetically pleasing living environment without realizing that the trees, green space, and gardens are actual "engineered" treatment systems to control stormwater runoff pollution.

Challenges of Stormwater Retrofitting

The "retrofitting" of an existing urban landscape has many challenges associated with it, including: space limitation and physical site constraints, the diversity of pollutants of concern, initial capital cost and long-term maintenance cost of the project, and public perception.

Space Limitation and Physical Site Constraints – Lack of available space is often a concern when designing urban stormwater retrofits. Site owners are reluctant to give up parking areas or reduce building footprints in order for retrofits to be installed. In addition, space that is available is often not suited for retrofit construction because of steep slopes, underground utilities, inability to drain site runoff, or the space is already an existing wetland or stream buffer. In addition, urban areas often have compacted soils which limit the infiltration potential at a site.

Pollutants of Concern – Total nitrogen, total phosphorus, and total suspended solids are often key pollutants of concern when designing retrofit projects. This is particularly true of the Chesapeake Bay - the largest estuary in the US and an extremely productive and complex ecosystem - where pollutant reduction goals have been established watershed-wide for all three pollutants. However, local limits on Total Maximum Daily Loads (TMDLs) often require municipalities to address other pollutants such as metals, oil and grease, chlorides, and bacteria. Different types of urban pollutants of concern require different design approaches or control techniques to work effectively. One cannot rely on standard design manuals or a "cookbook" approach for determining the most effective retrofit measures for an existing development.

Project Costs – Decreased taxes, grants, and other revenues, due to a sluggish economy, have made it difficult for many municipalities to adequately fund necessary retrofit projects. While the public may support the idea of clean water/air and protecting the environment, they are often unwilling to dedicate the funding required when it may mean fewer dollars will go to schools, infrastructure, fire and police services.

Public Perception – Lastly, public perception or acceptance is also often a challenge. In the older neighborhoods or well-established communities, residents are less receptive to give up recreational and open spaces they are accustomed to using for the purpose of stormwater retrofits. The fear of mosquitoes and other pest infestations is also a common reason for a community not to accept the installation of any densely vegetated water impounding stormwater structures as a retrofit option. Safety is also a concern in areas with young children and standing open water; therefore, innovative and extended public outreach and education are the keys to successful retrofitting of stormwater systems.

Parsons Brinckerhoff's Retrofit Experience

Parsons Brinckerhoff has extensive retrofit experience and three case studies highlighting different aspects of retrofitting design are featured below.

Biotrenches (also known as Bioswales) – Was Something Really Installed Here?? – As part of the Inter-County Connector Project in Maryland, $110M was committed to Environmental Stewardship and Compensatory Mitigation projects. A large portion of the sites identified under the Environmental Stewardship SWM Program were within older communities with grassed or asphalt lined swales, which conveyed stormwater runoff and discharged it to various receiving waters. Extensive community outreach was conducted as BMP concepts were developed. Since the home owners adjacent to the county roads maintain most of these swales and look at them as an extension to their yards, an innovative BMP had to be developed in order to meet both the water quality goals and the aesthetic/maintenance needs of the home owners. As a result, biotrench facilities were located within the existing roadside swales; once constructed they have an appearance similar to the existing swales.

The biotrench facilities promote infiltration of the first flush of runoff from impervious areas, enhance water quality, decrease thermal impacts to receiving streams, promote groundwater recharge, and reduce uncontrolled peak flows for smaller storm events. In areas with curbs and gutters, curb cuts were also incorporated into the design to aid in the reduction of stormwater runoff volumes and filter pollutants. Figure 1 shows the before, during, and after construction photos of biotrenches. Post-construction monitoring of these sites has shown the biotrenches to be very successful, with higher than expected water quality improvements.

Figure 1 – Biotrench construction in local neighborhoods before, during construction, and post construction.

Figure 2 – Permeable Pavers and Completed Bioretention Area

Tidal Back River Greening Projects – Bringing Water Quality Improvements to Neighborhoods, Schools, and the Local Community – During 2009-2010, Parsons Brinckerhoff conducted a Small Watershed Action Plan (SWAP) that identified over 80 retrofit activities to improve water quality within the Tidal Back River watershed in Maryland. In 2012, the design of retrofits for nine sites that had been identified in the plan began. The sites included seven schools, a local community center, and a park-and-ride facility. Each site was evaluated for retrofit potential and landscape plantings. Parsons Brinckerhoff worked with the Baltimore County Department of Sustainability to select the type and spacing of street and shade trees to be planted through the project sites. Retrofit BMP design included the removal of excessive impervious surface, installation of permeable pavers, reforestation, invasive species management, and the installation of bioretention facilities (see Figure 2).

One of the retrofit sites, the Mars Estates Elementary School, has a stream with a concrete channel at the edge of the property. Because funding and space were not available for a traditional stream restoration design, Parsons Brinckerhoff used an innovative design approach, drilling holes in the existing concrete channel to plant aquatic and stream bank grasses which will trap sediment, provide shading, and help to reduce the thermal impact of the concrete. This design will also improve the aesthetics of the stream (see Figure 3). The approach reduced design and construction costs and also made the permitting process easier. A public meeting was held to discuss these projects and they received overwhelming support from the community.

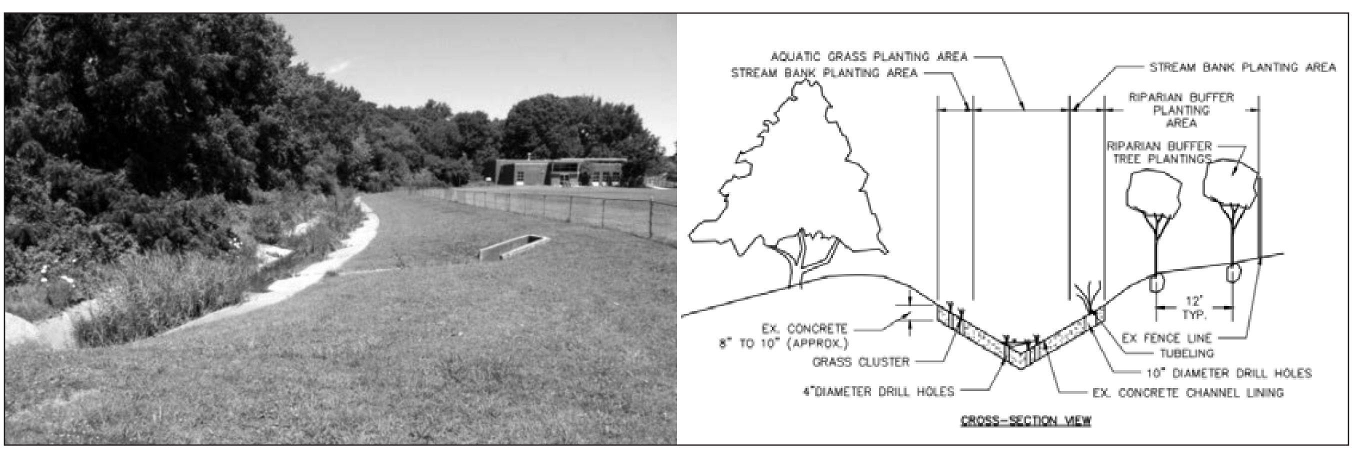


Figure 3 – The existing concrete channel is shown on the left and the proposed retrofit design is shown on the right.

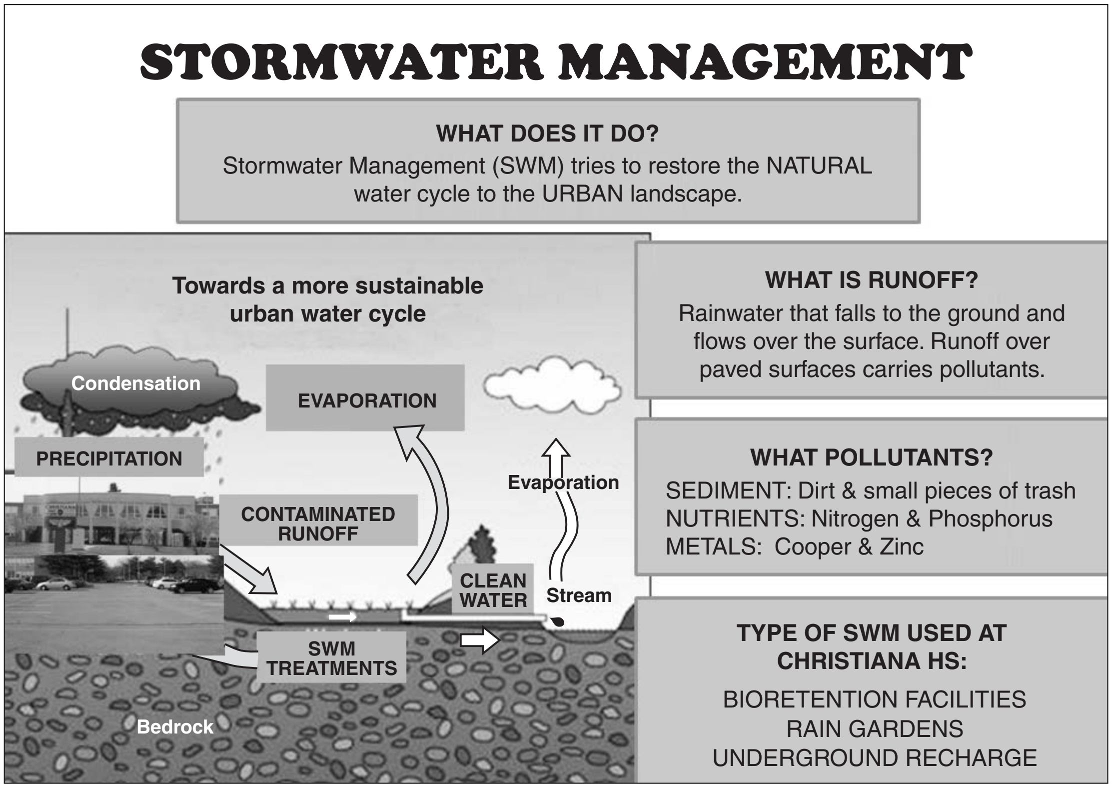


Figure 4 – Sample signage for the Christiana High School Water Quality Retrofits. (http:green.ccf.edu/stormwater.htm)

Christiana High School Retrofits – Blending Retrofits With Education – This retrofit project improved water quality through the implementation of a series of LID (low impact design) practices at a local high school in Delaware. The practices included installation of bioretention facilities, an underground recharge area, a rain garden at the school, and removal of impervious surfaces. In addition to the water quality benefits, Parsons Brinckerhoff is working with the Delaware Department of Transportation (project sponsor) to develop interpretive signage to help educate the students and visitors to the high school about the benefits of water quality retrofits (see Figure 4).

Conclusion

Although there are many challenges, retrofits have many positive benefits to a community. When designed properly, the facilities can be aesthetically pleasing as well as functional. Retrofits can help “green” a community and make it more livable.

***Kelly E. Lennon**, P.E., is a Supervising Water Resources Engineer with 16 years of experience. She is part of Parsons Brinckerhoff’s Water Technical Excellence Center (TEC) and serves as the Baltimore Water Group Manager.*

***Chin Y. Lien**, P.E., D.WRE, is a Senior Engineering Manager of Parsons Brinckerhoff's Water Technical Excellence Center (TEC) and he leads the water practice's technical leadership/ technology program.*

***Elizabeth Kanner**, P.E. was formerly Lead Water Resources Engineer in Parsons Brinckerhoff’s Baltimore office.*

Condition Assessment of Stormwater Channels - A Case Study for a Stormwater Asset Management Plan

by **James Chiang**, Sydney, AUS, +61 2 92725444, chiangj@pbworld.com; **Ramesh Seneviratne**, Sydney, AUS, +61 2 92725149, seneviratner@pbworld.com; **Nina Hames**, Sydney, AUS, +61 2 92725014, hamesn@pbworld.com; and **Pramod Janardhanan,** Sydney Water, Sydney AUS

This article presents an overview of the role of stormwater inspections in the development of a stormwater asset management plan. It outlines the complete set of processes and tools used for the condition assessment of stormwater channels and the innovative electronic presentation of results.

Using effective data capture technology allowed reliable and consistent observation and data recording. The observations recorded were efficiently and accurately transferred into the GIS database where the risks associated with each stormwater channel could be evaluated and managed, and repair and refurbishment could be ranked effectively.

Introduction

Sydney Water provides stormwater services to approximately 1.1 million people through more than 400km of stormwater network, mostly in the south and south-western suburbs of metropolitan Sydney, Australia. Sydney Water manages the network using an ongoing inspection program to provide an accurate condition assessment of each stormwater channel and help manage rectification works effectively.

Sydney Water engaged Parsons Brinckerhoff to inspect approximately 35km of open stormwater channels and 18km of closed stormwater channels over two years, from 2010 to 2012. This involved planning, inspecting, analysis, and condition assessment reporting on the nominated stormwater channels.

The project involved the key tasks that follow.

Planning

Planning the inspections involved data validation, field reconnaissance, developing a safety plan and work methodology (see Figure 1).

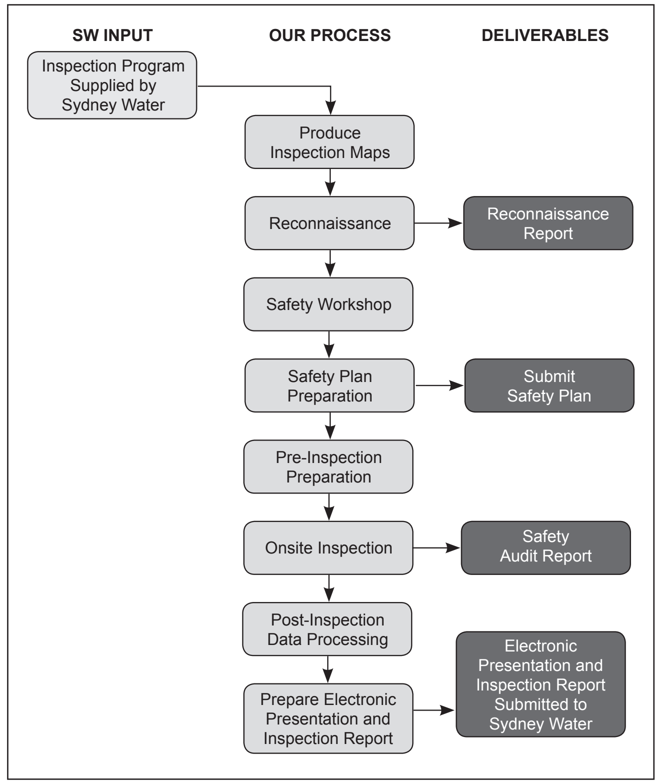


Figure 1 – Project methodology

Data validation

A desktop validation of the GIS data provided by Sydney Water was carried out before the field reconnaissance and inspection. An ownership check was made to confirm that only stormwater channels owned by Sydney Water were to be inspected.

Reconnaissance

Reconnaissance was an important component of planning the inspections to ensure they were carried out safely and efficiently. The onsite reconnaissance was used to identify potential safety issues and issues accessing the stormwater channel so these issues could be addressed before the inspection.

Safety

A safety workshop was held for Sydney Water and the inspection team to assess the hazards identified during reconnaissance. A safe work method statement (SWMS) was developed and used during inspections and helped the inspection team address hazards found on site.

Work methodology

Work methodology maps were produced that incorporated the outcomes of the reconnaissance and safety workshop. The maps identified the method in which the inspection team should traverse the stormwater channel, including what assets to inspect and in what order—entry and exit points and emergency exits. The maps improved efficiencies and reduced the time required in the field.

Inspection

Field inspections were made to observe and record the prevailing characteristics of the stormwater channel, and to make a risk assessment of defects.

Data capture method

Inspection engineers used a personal digital assistant (PDA) to capture and record observations in the field. A digital photograph was taken of each observation using a camera equipped with GPS.

The PDA device minimised processing of the data by:

- allowing easy capture of data through dropdown menus;
- allowing synchronisation of data with the GIS database in the office;
- organising captured data in such a way that it did not require manipulation or collation; and
- automatically calculating defect scores.

Inspection methodology

For safety reasons, a minimum of two engineers inspected the stormwater assets. To allow defects to be easily located at a later date, observations were recorded using an agreed convention:

- all inspections were conducted in an upstream direction;
- all photos were taken looking in an upstream direction;
- all observations had their geographic location recorded using a longitudinal chainage from an identified point of reference (inspection point);
- each inspection point was at an easily identifiable location along or adjacent to the stormwater channel (e.g., a road bridge); and
- the cross-sectional position of all observations was recorded using the clock-based orientation convention, as shown in Figure 2.

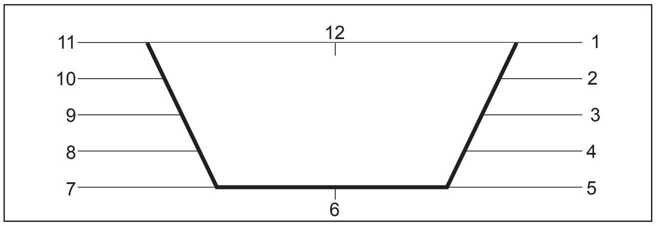


Figure 2 – Clock orientation convention (looking upstream)

Defect analysis

Defects were classified as either structural defects or serviceability defects. A structural defect is one that caused, or could cause, a failure of the stormwater channel structure, such as cracking. A serviceability defect is one that has reduced the flow capacity of the stormwater channel, such as siltation.

During the field inspection, an on-the-spot risk assessment was completed. For each defect, the likelihood of the defect causing failure and the consequence of that failure was determined. Refer to Figure 3 for a flowchart of the inspection and assessment methodology. Based on the probability of the defect failure occurring, each defect was assigned one of the following likelihoods:

- almost certain
- very likely
- likely
- unlikely
- improbable

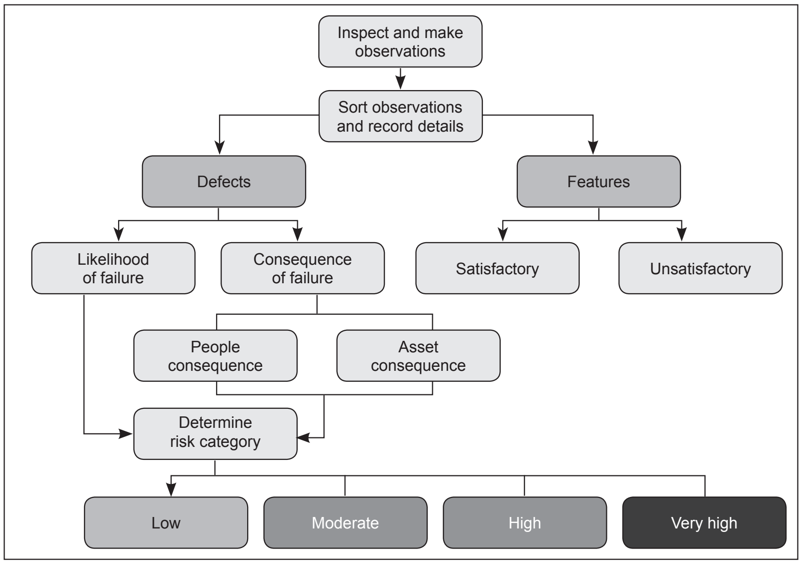


Figure 3 – Inspection and assessment methodology

Defect failure can have two types of consequences:

- people consequence – the potential to cause physical harm, injury, or death; and
- asset consequence – the potential to cause damage and/or loss of serviceability to assets.

For each defect, the people consequence and asset consequence were determined using the flowcharts in figures 4 and 5 respectively. The higher consequence was adopted as the overall consequence for the defect.

By using the risk assessment matrix shown in Table 1, the defect is assigned one of the following risk categories:

- very high
- high
- moderate
- low

Consequence of failure	Likelihood of failure				
	Almost certain	Very likely	Likely	Unlikely	Improbable
Catastrophic	Very high				
Major		High			
Moderate			Moderate		
Minor				Low	
Negligible					

Table 1 – Risk assessment matrix

To ensure accuracy, the risk assessment was done on site, while it could be observed.

Analysis

Defect scoring

Each defect was given a score based on the defect risk category, as shown in Table 2. Defect scores were applied on a per metre basis.

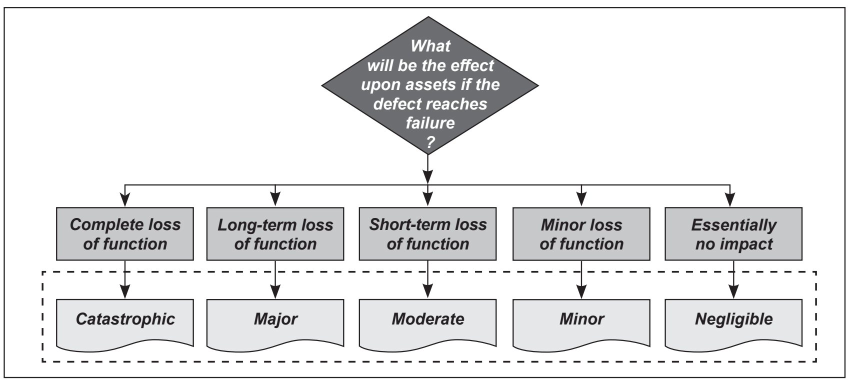


Figure 4 – Asset consequence flowchart

Risk Category	Risk Score/m
Low	1
Moderate	5
High	10
Very High	20

Table 2 – Defect scoring

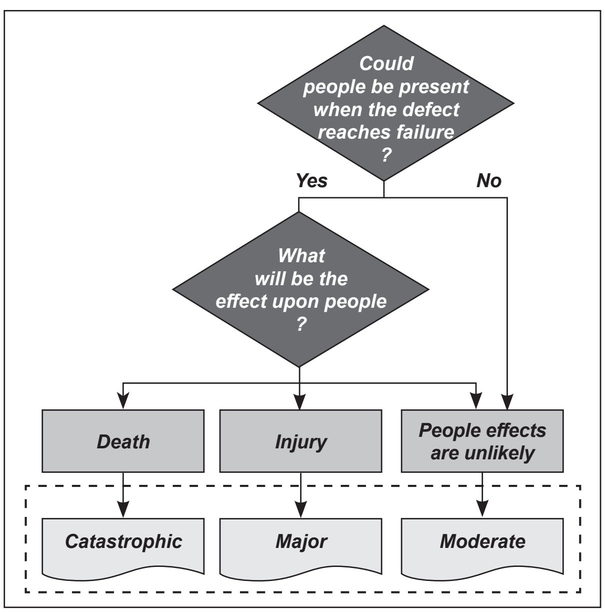


Figure 5 – People consequence flowchart

The individual defect score was calculated using the following equation:

$$Defect\ score = Risk\ score\ (/m)\ x\ length\ (m)$$

Grading assets

Each asset of the stormwater channel was given a structural and serviceability grade based on the number and type of defects per asset.

The grading is relative to the risk of each stormwater channel asset undergoing a structural or serviceability failure.

Defects were collated on an asset basis and a mean score for each asset was calculated to indicate the overall condition of the inspected channel.

The mean score was calculated by summing all the defect scores on each asset and dividing by the asset length as shown in the following equation:

$$Asset\ mean\ score = \sum_{i=1}^{n} \frac{x_i}{asset\ length\ (m)}$$

Customised GIS software was utilised to automatically calculate asset gradings. Once the mean score was calculated, the asset was assigned a structural grade and a serviceability grade between one and five using Table 3.

A grade of one indicates a low overall risk and a grade of five means failure of the asset is imminent or has occurred.

Reporting

Interactive software presentation

An interactive software presentation was generated for each stormwater channel inspection. The application does not require pre-installed software. The functions of the electronic presentation include the ability to:

- view results on an interactive map;
- toggle layers on and off and symbolise layers;
- display aerial photographs;
- click on observations on the map and show data and photographs;
- display colour coded asset grades; and
- generate individual defect reports.

Refer to Figure 6 for a screenshot of the interactive software presentation interface.

Inspection report

The findings of the inspection were used to produce an inspection report that:

- summarised the overall stormwater channel condition;
- summarised defect and feature observations;
- documented the inspection of the stormwater channel and the methodology used;
- assessed the risk associated with each unique defect;
- provided a structural and serviceability grading for each asset; and
- confirmed if the stormwater channels are open or covered.

Asset management plan

The inspection program provided accurate details and a condition status for each stormwater channel. This was part of a complete set of processes and tools for asset management that cover a full spectrum of activities, from condition monitoring and the documentation of individual assets to return on investment analysis.

This information helped Sydney Water prepare a maintenance program and develop business cases for renewal works.

Conclusion

The project methodology for recording defects focused on achieving a reliable record of the defects in Sydney Water's stormwater channels. There were two key elements to achieving successful project outcomes:

Grade	Deterioration level	Appropriate response	Mean score
1	Insignificant	• No immediate action • Monitor as for standard asset management practices	0 – 1
2	Minor	• No immediate action • Monitor as for standard asset management practices	>1 – 5
3	Moderate	• Monitor as for standard asset management practices • Medium-team rehabilitation required	>5 – 10
4	Serious	• Make immediate risk assessment • Immediately respond to identified risks • Make appropriate investigations • Use short-term rehabilitation	>10 – 15
5	Imminent Failure OR Failure has occurred	• Make immediate risk assessment • Urgently respond to identified risks • Urgently investigate • Immediately rehabilitate	>15

Table 3 – Asset grading

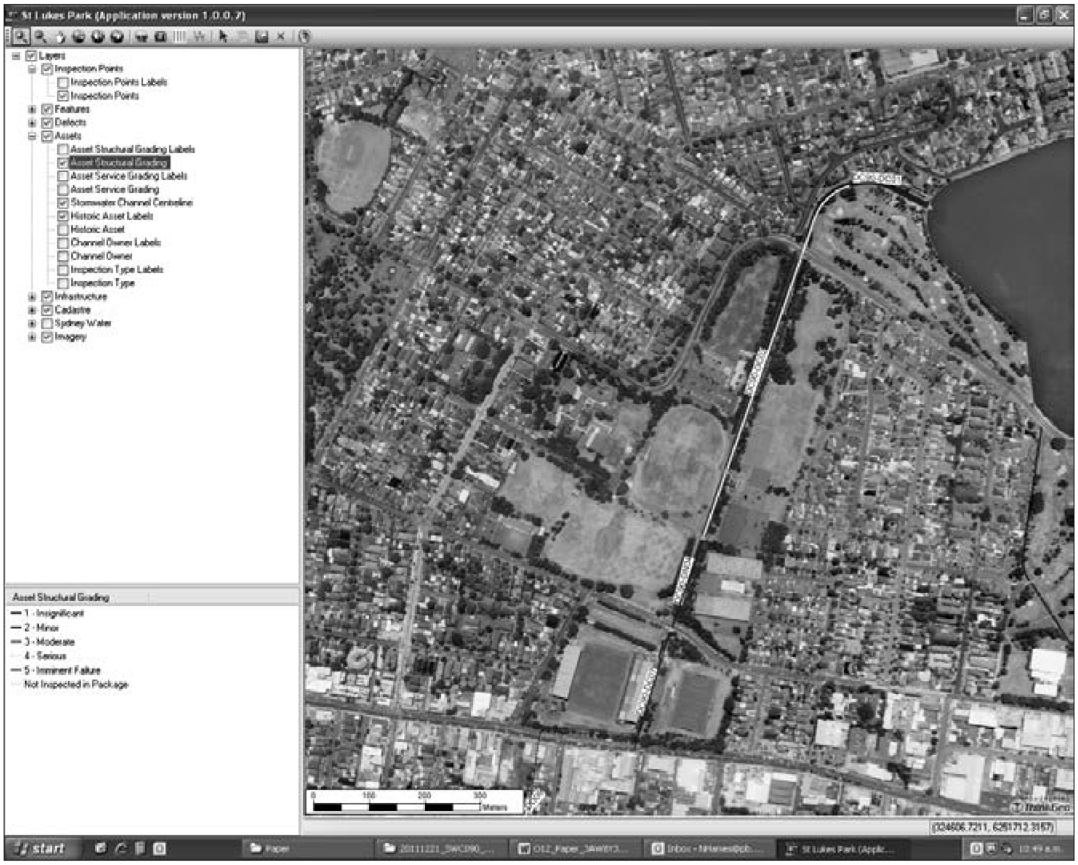


Figure 6 – Screenshort of Interactive Software Presentation Interface

1. reliable and uniform observation and recording of defects to evaluate risks to the overall operation of stormwater assets; and
2. effective data capture technology and tools to transfer observations recorded efficiently and accurately into Sydney Water's GIS database.

These outcomes allowed Sydney Water to manage the risks associated with each stormwater channel, and effectively rank repairs or refurbishments. Sydney Water could deliver value for money in the ongoing operation of these assets by not compromising the safety of people, the surrounding infrastructure, and the operational capacity.

[The authors gratefully acknowledge Sydney Water's permission to use information from the Inspection of Open and Traversable Stormwater Channels project in this paper.]

James Chiang *is a Principal Water Engineer with more than 35 years of experience in the water industry. He has successfully led and implemented programs for major rehabilitation, amplification, and upgrading of sewer collection infrastructure.*

Ramesh Seneviratne *is a Senior Water Engineer and Project Manager with more than 14 years of experience in the water industry, primarily in asset management. He has successfully managed implementation of Sydney Water's stormwater channel inspection project for the past 4 years.*

Nina Hames *is an emerging Civil Engineer, with 3 years of experience in the water industry. She has been involved in Sydney Water's stormwater inspections project since its inception in 2010.*

Pramod Janardhanan *is an Environmental Engineer and the Asset Manager for Sydney Water. He manages the condition assessment program and capital works program for Sydney Water's stormwater assets.*

Green Stormwater Infrastructure (GSI) on an Urban Arterial

by **Tye Simpson**, Seattle, WA, US, 1-206-382-8316, simpsont@pbworld.com; **Adam Lee**, Portland, OR, US, 1-503-478-2823, leeab@pbworld.com; and **Jared Nakamoto**, Seattle, WA, US, 1-206-382-6341, nakamoto@pbworld.com

On March 6, 2013, the mayor of Seattle announced a new goal—to manage 700 million gallons of stormwater annually with green stormwater infrastructure (GSI) by the year 2025. Due to the topographic conditions in Seattle, with many landslide prone slopes and the geologic conditions, with many areas underlain by a low permeability layer of soil (i.e., glacial till or hardpan), the goal of handling approximately 70 percent of the rainfall volume with GSI practices appears ambitious. Regardless, this initiative underscores the emphasis that the city is placing on the use of green stormwater practices for treating and controlling runoff.

The city of Seattle has been on the forefront of low impact development (LID) techniques utilizing green infrastructure since the early 2000s when it began implementing natural drainage system (NDS) designs in areas discharging to sensitive and degraded creeks. Seattle's Street Edge Alternatives (SEA Streets) and "110th Cascade" projects employed creative and effective methods of reducing impervious areas and providing natural water quality and detention benefits. After over a decade of collecting monitoring data on these projects, study results have shown that they reduced runoff volumes by over 98 percent during the rainy season. Now the city is looking to expand these successes to projects throughout the city wherever it is possible.

Not only is GSI helping Seattle address the runoff impacts from development, it also serves to bring back elements important to maintaining the hydrologic cycle. The requirement for utilizing GSI on projects with more than 2,000 square feet of new or replaced impervious surface was added to the city's 2009 Stormwater Code with the intent to "reduce the effects of development on receiving water temperature and move the city towards re-establishing lost vegetation in fully developed areas."

The difficulty in implementing GSI on projects where site conditions are less than ideal was recognized, and the city qualified its GSI requirement with the phrase "to the maximum extent feasible" (MEF). The Seattle Stormwater Manual defines MEF as follows: "the requirement is to be fully implemented, constrained only by the physical limitations of the site, practical considerations of engineering design, and reasonable considerations of financial costs and environmental impacts."

AAC North 105th Street and Northgate Way Project – GSI to the MEF

The purpose of the project is to improve the four lane corridor along N 105th Street and N/NE Northgate Way from Greenwood Ave N to Lake City Way NE. Improvements will include 1.4 miles of roadway repaving, new sidewalks and curb ramps, drainage improvements, street lighting and traffic signals, and intelligent transportation system (ITS) components. In late 2011, the Seattle Department of Transportation (SDOT) selected Parsons Brinckerhoff to design the drainage system improvements for the project. All other design services for the project were performed in-house by SDOT staff.

The professional drainage design services provided by Parsons Brinckerhoff included drainage reports, plans, profiles, details, special provision specifications, construction cost estimates, and construction support services. The project was advertised for construction in the first quarter of 2013 and construction began in July 2013. The construction bid for the project was $9.1 million with approximately 25 percent of the total construction costs related to the drainage improvements. The project lies within separated sewer drainage basins in north Seattle. Two of the basins discharge to creek basins, Thornton and Pipers creeks, and a third lies within the Densmore Lake Basin. Although the project does not add any new impervious surface area, it involves replacing roadway and sidewalk surfaces well above the 'trigger' amounts requiring flow control and treatment. All three basins required both stormwater flow control and water quality treatment. The project also triggered the requirement to utilize GSI to the

MEF with a goal of mitigating 100 percent of the downstream impacts from the replaced impervious surfaces. In the event that less than the 100 percent goal is realized, documentation must be provided to justify the lower mitigation percentage. Allowable justifications are: engineering limitations (low infiltration rates, flooding potential), physical limitations (utility conflicts, steep slopes, intended use of right-of-way), or excessive financial costs (additional cost estimates are required).

Evaluating the Feasibility OF GSI

The project was very constrained on what GSI best management practices (BMPs) could be utilized to meet the 100 percent mitigation goal. The right-of-way (ROW) was very narrow and allowed for only five foot sidewalks and three foot planter strips along much of the project.

Although the drainage design team worked to minimize impacts to trees during design, a walkthrough of the project with the city's arborist at the 90 percent complete stage was made to identify any additional modifications that could be made to the design to minimize impacts to trees. This walkthrough identified several modifications to the drainage design to be made to reduce the risk of root damage from excavation. The retention of the existing trees was used to partially meet the city's GSI requirement. Additionally, new trees were added, mitigating up to 50 square feet of impervious surface per tree (Figure 1).

Figure 1 – SDOT Northgate and 5th Project Tree Filter System

Infiltration GSI BMPs were not considered feasible due to the fact that the planter strips are too narrow, approximately three feet in width, to allow for bioretention planters. The city does not consider below-grade infiltration systems to be a GSI BMP, and therefore buried infiltration systems were not used.

As an impervious surface reduction method, porous concrete was used where allowed by city code - only on sidewalks having less than a 5 percent longitudinal slope. Around 20 percent of the concrete sidewalks added by the project met this code requirement. Approximately 11,000 square feet of impervious surfaces were mitigated through existing and new tree canopy, and 10,750 square feet of impervious surfaces were mitigated through the use of porous concrete surfaces. This resulted in 9.5 percent of the 5.2 acres of new plus replaced impervious surfaces being mitigated utilizing GSI. GSI to the MEF documentation, included in the stormwater technical information report (TIR) prepared for city approval, demonstrated that there were no other GSI BMPs that were feasible for the project.

Project Flow Control Requirements

The city code requires that a continuous hydrologic model be performed to confirm that the flow control targets are met even if the project had achieved the 100 percent mitigation of the new plus replaced impervious surfaces using GSI BMPs. In areas with low permeability, as is the case in most of Seattle, additional flow control would typically still be required. The project achieved only minor reduction in the required flow control volumes using GSI BMPs, and the project utilized five stormwater detention pipes, ranging in diameter from 60 to 84 inches, to meet the remaining flow control requirement.

The challenge of sizing the stormwater detention facilities for the creek basins was in meeting the very restrictive release rate requirements and minimum orifice size. The requirement was for developed runoff to match a pre-developed condition modeled as a pasture[1] and that the minimum orifice size in the flow control structure be ½ inch in diameter to reduce the risk of clogging. This results in the need for relatively long detention pipes in order to provide the required detention volume without having the additional hydraulic head that a larger diameter pipe would place on the ½ inch orifice.

[1]The city's stormwater standards treat flow control as a method for reducing the degradation of water bodies, in particular the increase in erosion and adverse stream channel alterations due largely to an increase in runoff volumes and not peak flows, as a result of development. To slow this degradation, the city requires a project's post development hydrologic conditions (volume, rate, duration, frequency) match a reasonable natural condition. If the site is forested (unlikely in Seattle city limits) or the project lies within a sensitive creek basin, it must match forested conditions prior to development. Most other areas of the city are required to match a pasture condition, which allows a compromise between matching existing developed conditions and forested conditions.

One of the detention pipes was approximately 600 feet long in order to provide the required volume without exceeding the allowable flow rates by increasing the head on the ½ inch orifice. The 600 foot long, 48 inch pipe was designed to be placed under or over 12 different utilities including a water main, sewer main, and a 16 inch high pressure gas main; and it was sandwiched in a 12 foot wide corridor with an existing storm line on one side and the right-of-way line on the other. Additionally, the city does not allow detention pipes to be reduced in size as they enter a maintenance hole, as some jurisdictions allow. This resulted in maintenance holes up to 10 feet in diameter being required (see Figure 2). The use of three dimensional modeling was essential in locating the detention pipes in such a heavily congested utility corridor.

Figure 2 – Detention Pipe Maintenance Hole for SDOT 105th TIB Project. The flow control maintenance hole in this photo was moved further away from the existing tree to avoid cutting into key roots so that the tree could be retained.

Project Treatment Requirements

Because the amount of replaced pollution-generating impervious surface in all three drainage basins exceeded 5,000 square feet, the project was required to provide basic water quality treatment in all basins. One roadway intersection of the project was additionally subject to oil control treatment since two legs of the intersection exceeded an average annual daily traffic (ADT) volume of 15,000. The types of treatment BMPs that are available for use on a roadway which is built out to the full right-of-way width are extremely limited.

Most non-proprietary treatment BMPs, for example wet ponds, sand filters, etc., are not possible due to a lack of space. For this project, only proprietary systems pre-approved by the city were feasible. Water quality treatment was met through the use of the following proprietary treatment BMPs:

- 17 Filterra™ catch basins – bioretention and filtration units utilizing a tree's root system with mulch and filter media, contained within a catch basin. Three units were placed at the high-use intersection providing basic treatment and oil treatment. (See Figure 3.)
- 8 StormFilter™ maintenance holes – a stormwater filtration device utilizing filter cartridges placed within a maintenance hole.
- 2 StormFilter™ catch basins – a stormwater filtration device utilizing filter cartridges placed within a catch basin.
- 1 BayFilter™ maintenance hole – a stormwater filtration device utilizing filter cartridges placed within a maintenance hole. This BMP has conditional approval and, at the city's request, was added as a test case for the city.
- 1 Perk Filter™ maintenance hole – a stormwater filtration device utilizing filter cartridges placed within a maintenance hole. This BMP also has conditional approval and, at the city's request, was added as a test case for the city.

Figure 3 – Installation of a Filterra™ Catch Basin.

Conclusion

As is the case on many roadway projects when ROW space is very limited, achieving the city's GSI to the MEF requirement of 100 percent mitigation was not feasible. While GSI is desirable, the current limitation on both the use of porous pavement in the roadway and below-grade infiltration in the city make it difficult for more than a small percentage of the GSI target to be achieved on an urban roadway. The use of proprietary treatment systems and buried detention pipes are largely a necessity on pavement rehabilitation projects in the city due to space constraints and generally very poor soils for infiltration.

However, it is a step in the right direction for the city to require evaluation of GSI and, as the process and the technology develop, it will be interesting to see if the mitigated percentages begin to increase to meet the mayor's goal of managing 70 percent of the annual rainfall volume utilizing GSI.

The city's assigned project engineer called this one of the most complicated drainage projects he has encountered in his time with the city. Both the city's engineer and the project manager rated Parsons Brinckerhoff's performance on the project as 9 out of 10 (excellent).

Tye Simpson *is the Northwest Water Area Manager and he has over 23 years of design experience. He has given presentations on green stormwater infrastructure and low impact development at various conferences and seminars.*

Jared Nakamoto *has six years of experience in both traffic and stormwater design. He provided the design and drafting on the SDOT project utilizing Autodesk Civil 3D.*

Adam Lee *has seven years of experience in civil site design, with a focus on stormwater and low-impact design. He has been involved in several projects utilizing green stormwater infrastructure and is currently designing the collection and treatment system on a roadway project that includes 6,000 linear feet of bioretention planters, as well as basins, swales, and mechanical filtration devices.*

Planning for Greener, Cleaner, and More Livable Communities Through Watershed Management

by **Kelly E. Lennon**, Baltimore, MD, US, 1-410-385-4162, lennonk@pbworld.com; and
Everett Gupton, Baltimore, MD, US, 1-410-385-4145, gupton@pbworld.com

Introduction

In the 21st century, solving the complex environmental issues that affect a community requires an innovative approach that not only utilizes the most current technologies, but also engages community members. For the past four years, Parsons Brinckerhoff has worked with Baltimore County, Maryland to develop detailed restoration plans for several sensitive watersheds in an effort to satisfy environmental program requirements while meeting citizens' needs for a healthy environment, clean water, and an aesthetically pleasing community. These restoration plans, called Small Watershed Action Plans (SWAPs), identify strategies to accomplish this vision, including a combination of government capital projects, actions in partnership with local watershed associations, citizen awareness campaigns, and volunteer activities. This article highlights how Parsons Brinckerhoff team members in the Baltimore, MD office worked with Baltimore County to develop a Small Watershed Action Plan for the Middle River and Tidal Gunpowder (MRTG) watershed in Essex, MD.

Watershed Overview

Baltimore County consists of 14 major watersheds covering over 680 square miles and containing a variety of land uses ranging from highly urban to agricultural. This variety means that solutions that might work in one end of the county might not be applicable in another area where the natural and manmade characteristics can be completely different. Therefore, the first step in developing a local restoration plan is the characterization of the local watershed.

Geographic Information System (GIS) Analysis

The study area for the MRTG watershed (shown in Figure 1) is located on 19.3 square miles of area which is directly adjacent to tidal waters of the Middle and Gunpowder rivers. Through extensive GIS analyses, Parsons Brinckerhoff was able to classify many of the natural and manmade aspects of this area. Analyses of natural characteristics include such items as forest cover, geology and soils, stream systems, and shoreline conditions. Analyses of the human-modified landscape include topics such as land use, impervious cover, and population. The MRTG study area is comprised mostly of forests (34%), wetlands (8%), and residential areas (33%). In addition, 17% of the watershed is classified as impervious, or incapable of being penetrated by water. Figure 2 contains a map created from land use data provided by the county.

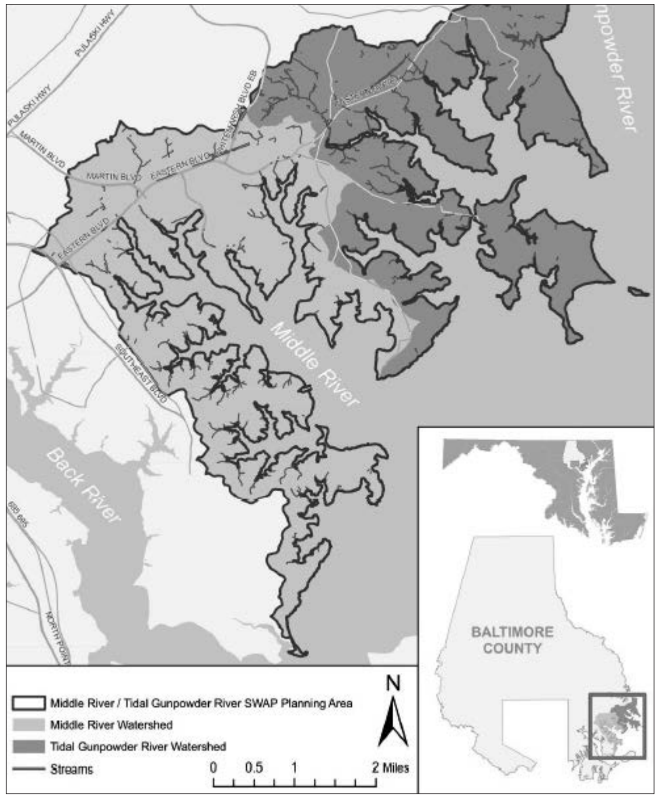


Figure 1 – Middle River & Tidal Gunpowder Watershed

Upland Analysis

In addition to developing a thorough analysis of the characteristics and key components of the watershed, Parsons Brinckerhoff staff conducted extensive field reconnaissance of the study area. This field research included

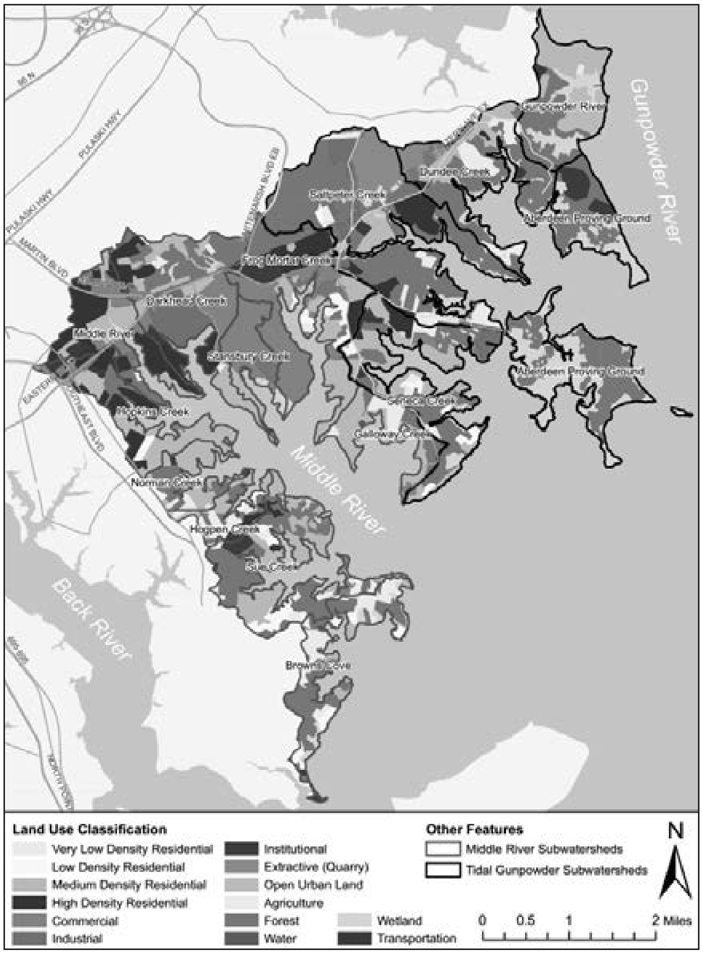


Figure 2 – MRTG Watershed Land Use Map

studies of the neighborhoods, institutions, businesses that make up the developed portions of the watershed, and natural features such as streams and shoreline, as well as site visits to some of the large landowners in the watershed (see Figure 3). The purpose of the field visits was to identify restoration opportunities within the watershed. These restoration opportunities would then

Figure 3 – Field Team Conducting Reconnaissance Visit

be catalogued and included as part of the strategy for meeting not only regulatory requirements, but the vision and goals of the local community.

Regulatory Requirements

Many environmental requirements are in place to protect and improve local waterways and ensure restoration will occur in the Chesapeake Bay. SWAPS are developed in part to provide Baltimore County with a framework to meet these requirements. For the MRTG watershed, environmental requirements include:

- National Pollutant Discharge Elimination System (NPDES) Stormwater Program permitting and planning requirements for municipal separate storm sewer systems (MS4s) - The county's NPDES permit requires the development of a systematic assessment of water quality and restoration plans for all its watersheds.
- Total maximum daily load (TMDL) reductions for MRTG - MRTG tidal waters are listed by the US Environmental Protection Agency (EPA) as impaired by nutrients, sediment, and PCBs in tidal areas, though no TMDL has been developed for any pollutant in the study area.
- TMDLs for the Chesapeake Bay for nutrient and sediment reductions - Nutrient and sediment load reductions are assigned on a county basis for achievement by 2025 with significant progress (~60% of the required reduction) to be completed by 2017. Table 1 lists pollutant load reduction requirements for the MRTG watershed, under the Chesapeake Bay TMDL.

TMDL Pollutant	*2017*	*2020*
Nitrogen	*20.3%*	*29.0%*
Phosphorous	*31.6%*	*45.1%*

Table 1: Pollutant Load Reduction Requirements for Baltimore County (SWAP, 5)

Community Engagement

Successful watershed restoration requires involvement and participation by all sectors of a community, from government to private sector businesses, and volunteer watershed associations. In anticipation of tighter budget restraints and less assistance from federal agencies, the importance of community involvement will only increase in the future.

For over a year, project members from Parsons Brinckerhoff led a steering committee consisting of county personnel and leaders from the community who worked together to engage the community and develop a successful SWAP. The community leaders included members of local business associations and home owner association representatives, as well as local watershed associations. The committee met bimonthly throughout SWAP development, and held three stakeholder meetings for the general public to provide updates and solicit input on the plan.

One task of the committee was the development of a document called SWAP Vision, Goals, and Objectives which guides what restoration actions would be chosen for the watershed. Goals were listed under categories that included: clean water, forests and habitat, preservation, and recreation.

A series of objectives were developed to ensure that each goal would be met. Action strategies described the method that would be used to achieve the objective and, ultimately, the associated goal.

Allowing the committee to develop goals and objectives it believes in results in support of the work that needs to be completed to meet the SWAP goals and pollutant reductions. The goals developed by the community for the MRTG watershed area are as follows:

- improve and maintain clean water;
- reduce pollution from stormwater runoff;
- reduce trash and dumping;
- increase buffer zones along streams and shorelines;
- increase tree cover and promote healthy and sustainable forests;
- increase tidal and non-tidal wetlands for improved terrestrial habitat;
- improve shallow water habitat along shoreline;
- protect and maintain submerged aquatic vegetation (SAV);
- increase the amount of land in preservation;
- improve and maintain access to waterways for recreational boating; and
- promote the region as a desirable waterfront destination for residents, boaters, and visitors.

The majority of these goals address the regulatory requirements this watershed is subject to, but goals addressing recreation and the waterfront economy were a direct result of the engagement of the public.

Another way to engage the community was to provide inhabitants with an easy way to alert the county of concerns within their watershed. Parsons Brinckerhoff developed a "blue card" that allowed residents to check off the type of problem they were experiencing (trash dumping, illicit discharge, flooding, etc.) and provide a specific location and description. The benefits of the blue cards were two-fold—they provided the field crews with a list of problem areas to investigate and they kept the flow of the public meeting moving while giving the residents an easy way to voice their concerns. The county tried to address as many items on the blue cards as possible prior to the next stakeholder meeting so that the residents could see that real progress was being made in their watershed.

Restoration and Preservation Options

To meet regulatory requirements and address goals set by the county and the local public, a series of restoration and preservation opportunities were developed which included:

Municipal Capital Programs

These are projects and purchases that the county can undertake in the short-term to improve water quality in the Middle River and Tidal Gunpowder watersheds. These projects include innovative stormwater retrofits implementing low-impact development (LID) techniques to treat existing impervious areas, stream restoration projects to enhance or re-establish a healthy stream network, and shoreline enhancement projects. Parsons Brinckerhoff has provided final design on several municipal capital projects which its team members identified early on during the SWAP process.

Municipal Management Programs

These are longer-term or continuous actions that the county can take to improve water quality in the Middle River and Tidal Gunpowder watersheds and can include expanding existing programs, such as street sweeping, or identifying new ways for the county to achieve tree planting projects in the watershed.

Volunteer Restoration Programs

These programs include activities or projects supported by the county but conducted by volunteers and volunteer organizations, such as a watershed improvement group. Each of the watersheds in Baltimore County has a dedicated watershed association of environmentally conscientious citizens who conduct stream cleanups, tree plantings, and educational presentations. Parsons Brinckerhoff provides these groups with targeted planting and clean up areas to maximize the positive impacts they create within their watershed and community.

Business and Institutional Initiatives

Although many businesses and industrial landowners already conduct environmentally beneficial activities, Parsons Brinckerhoff provided Baltimore County with a targeted approach to engaging the business community in watershed restoration initiatives by identifying opportunities and providing the education necessary to carrying them out.

Citizen Awareness Activities

These are actions that any resident or citizen in the watershed can take to provide a benefit to water quality. Parsons Brinckerhoff provided education to a number of community members during public meetings on ways they can help their community.

Conclusion

By engaging the community throughout the development of the SWAP, Parsons Brinckerhoff was able to prepare a list of more than 70 restoration activities that could be implemented within the watershed to help achieve the desired pollutant load reductions and to help meet the Chesapeake Bay TMDLs. Implementing the full range of action items will cost the county approximately $20 million and will yield load reductions of almost 6,000 lbs per year of total nitrogen and almost 700 lbs per year of total phosphorus. By engaging the community and local businesses throughout the development of the SWAP, Parsons Brinckerhoff was able to develop an innovative and unique plan that directly addressed the needs of each distinctive watershed and the community it supports.

Parsons Brinckerhoff currently holds a multi-year, On-Call Watershed Planning Contract with the Baltimore County Department of Environmental Protection and Sustainability. To date, Parsons Brinckerhoff has completed four separate Small Watershed Action Plans, three of which involved tidally-influenced watersheds, and is currently developing its fifth plan for an upland watershed which should be completed in 2014. In addition, Parsons Brinckerhoff has performed similar studies for Baltimore City Department of Public Works and the Prince William County Virginia Department of Public Works.

Kelly E. Lennon *is a Supervising Water Resources Engineer with 16 years of experience. She is part of Parsons Brinckerhoff's Water Technical Excellence Center (TEC) and serves as the Baltimore Water Group Manager. She was Project Manager for five Small Watershed Action Plans (SWAP) for Baltimore County.*

Everett Gupton *is a Senior Water Resources Engineer within Parsons Brinckerhoff's Raleigh, NC office and has served as Task Manager for three Small Watershed Action Plans (SWAP) for Baltimore County.*

Raising Public Awareness about Water Quality

by **Kelley (Stanka) Moxley**, Baltimore, MD, US, 1-410-246-0530, stankak@pbworld.com;
and **Stefany Wang**, Baltimore, MD, US, 1-410-752-9623, wangst@pbworld.com

The public has a vital role to play in protecting the nation's water resources. Many cities and towns in the US have separate storm drain and domestic wastewater sewer systems. This means that anything that goes into the storm drain system goes directly to an ocean or river without first passing through a wastewater treatment system. Through public outreach efforts that include educating children at a young age and encouraging community involvement, we can all take steps to ensure that our streams and oceans remain clean for future generations. Parsons Brinckerhoff has contributed to the creative efforts of raising public awareness about water quality through innovative collaboration endeavors with the Hawaii Department of Transportation, Delaware Department of Transportation, and Baltimore County in Maryland.

Figure 1 – Parsons Brinckerhoff staff helps to educate children about stormwater pollution through fun activities at a local event in Hawaii.

Public Outreach through Youth Education

Hawaii

As part of the Hawaii Department of Transportation's (HIDOT) effort to bring the state's stormwater management program into full compliance with federal requirements, Parsons Brinckerhoff provided program management and technical services which included:

- developing an inventory of stormwater facilities;
- conducting condition inspection and assessment of drainage infrastructure;
- managing maintenance and construction activities;
- implementing a water quality monitoring program;
- conducting erosion control and retrofit studies;
- developing statewide stormwater management and pollution prevention guidelines, criteria, and manuals;
- designing water quality improvement projects;
- implementing pollution prevention measures; and
- developing public education and outreach activities.

HIDOT believes it's never too early to begin educating the children of the community, and so the Parsons Brinckerhoff Honolulu office currently coordinates public education and outreach activities with HIDOT by arranging community and school events each year to raise public awareness about water quality and stormwater pollution (see Figure 1). A project lead at the Parsons Brinckerhoff Honolulu office believes that "through educating Hawaii's children about stormwater awareness, we're teaching the next generation how they can 'Malama I Ka Wai' (protect our water), one child at a time." Educating the children about reducing stormwater pollution can in turn help to educate the parents and change the perspective of the current generation.

Figure 2 – A sticker book about protecting the waters of Hawaii.

The events often focus on the children, and activities have included a stormwater booth where children learn the importance of keeping Hawaii's waters clean through sensible everyday choices at their homes and schools. The children are taught about safety near stormwater infrastructure. They play games that encourage them to think about the impact of trash on stormwater, and each child receives a reusable goodie bag with fun and educational material (Figure 2). Totes filled with educational material are also given to the teachers to encourage them to incorporate lessons about stormwater into their everyday curriculum.

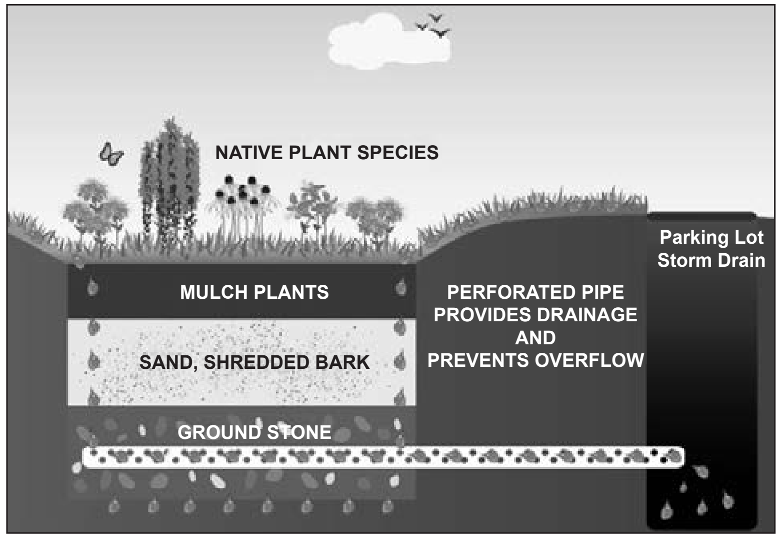


Figure 3 – Example of a bioretention facility

Delaware

The Delaware Department of Transportation (DelDOT) embarked on a similar agenda to HIDOT's, but its goal was to educate high school students (grades 9-12). As part of DelDOT's stormwater program, Parsons Brinckerhoff is implementing low impact development (LID) practices at Christiana High School in New Castle County, Delaware. LID is a design approach to managing stormwater that emphasizes conservation and use of on-site natural features to protect water quality. The retrofit projects include installation of bioretention facilities (see Figure 3) and rain gardens to treat stormwater runoff from the school roof and parking lot before it reaches the storm drain system. The bioretention facilities consist of layers of plantings, mulch, filter media, sand, and gravel to filter pollutants from the stormwater runoff.

To raise awareness and educate the students about the importance of stormwater treatment, Parsons Brinckerhoff developed and incorporated interpretive signs which describe the functions and benefits of each type of facility and treatment component. The signs explain concepts such as: the meaning of rainfall runoff; how the natural hydrologic cycle is transformed into a high-runoff urban hydrologic cycle in developed areas; and the goals and benefits of stormwater management. The main components of bioretention facilities and rain gardens—from nutrient uptake by the native vegetative plantings, to filtration of pollutants through the biosoil filter media, to groundwater recharge through the facility bottom—are also explained. Parsons Brinckerhoff designed the initial concept and content of the interpretive signs and coordinated with DelDOT and the Partnership for the Delaware Estuary to refine the language and graphics to make them even more beneficial to the target audience.

Public Outreach Through Coordination with Public Officials and Community Leaders

Baltimore, MD

In 2009, Parsons Brinckerhoff was contracted by the Baltimore County Department of Environmental Protection and Sustainability (EPS) to develop a Small Watershed Action Plan (SWAP) for the Tidal Back River watershed in Baltimore County, MD.

Public outreach and community involvement were key components to the success of the project and community and business leaders were invited to participate on a watershed steering committee (see Figure 4). Parsons Brinckerhoff and officials of Baltimore County led the steering committee and were able to get the message out about the project so each of the public stakeholder meetings had more than 150 people in attendance. The committee helped generate public support and awareness by connecting the project to a strong local cause. For example, residents in the Tidal Back

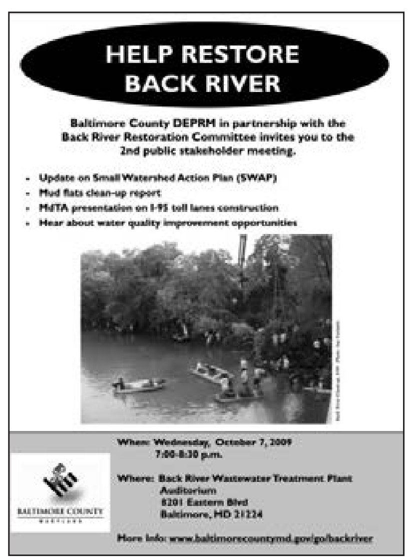


Figure 4 – Flyer inviting local residents to the upcoming stakeholder meeting.

KIM HAIRSTON/BALTIMORE SUN PHOTOS

Maryland Attorney General Douglas F. Gansler and Baltimore County Council Chairman John Olszewski Sr., third and fourth from left, see for themselves the amount of trash scooped out of Back River.

On Back River tour, a lot of trash talk

Residents complain to Gansler about litter problem

By Mary Gail Hare
THE BALTIMORE SUN

All of Baltimore's uncollected trash — from the bottles tossed into storm drains to the litter dropped carelessly on the streets — seems to wash into Back River.

At least, that's the way it looks to residents along the eastern Baltimore County waterway.

A trash boom installed a year ago was filled Thursday with bottles, tires, balls, logs, even a small appliance. Crews will remove all that debris to prevent it from flowing downstream into the Chesapeake Bay. But the task is never-ending, especially af-

maintain it through the year. The County Council recently awarded a $70,000 grant to the Back River Restoration Committee, which takes over the boom operation May 1.

Next, Schilpp said, he wants to tackle marshlands that in the 1930s and 1940s became dumping grounds for many companies operating along the river.

"Maybe the attorney general can assist us with this and get others on board," Schilpp said.

Gansler's visit included a boat ride to Hart Miller Island, a wildlife refuge and recreational area at the mouths of Back and Middle rivers as they flow into the bay. He also toured the plant on Eastern Avenue

Figure 5 – News article about Back River trash

River watershed complained about a significant trash problem (see Figure 5) in the area. The county provided dumpsters and debris pick-up, and also installed an experimental trash boom and provided access to boats to clean up the tidal portions of the Back River. Local newspapers reported on the amount of trash the boom cleaned up in the river, which totaled 340,000 pounds of trash and 2500 tires in its first year of operation. This success generated further public support for restoration of the Tidal Back River watershed.

At stakeholder meetings, the county continued to listen to concerns of the community and respond to them. For example, in response to complaints about a growing midge (a type of insect) problem, the county organized a subcommittee that reached out to Towson University Department of Biological Sciences to investigate the problem, identify prevalent midge species, and conduct investigations for mitigation alternatives, balance studies, and control options.

With input from the steering committee, a slogan—"Scenic Back River - Discover the Hidden Treasure"—was selected by citizens of the local neighborhoods by vote, and it was important in rallying the Back River communities behind a common cause. Additionally, keeping the community informed about the county's measures to protect the waters of Back River helped to engage the public's interest and generate support for the project. For example, during the stakeholder meetings, the county discussed its trash management plans, and representatives from the Maryland Transportation Authority (MdTA) gave a presentation on erosion and sediment control measures that were employed during the I-95 toll lanes construction.

Parsons Brinckerhoff's Role

Parsons Brinckerhoff Water Technical Excellence Center is involved in raising awareness about water quality and reducing stormwater pollution through its public outreach initiatives. In Hawaii and Delaware, Parsons Brinckerhoff developed education and outreach activities aimed specifically at students in kindergarten through twelfth grade (K-12). In Baltimore, Parsons Brinckerhoff facilitated communication among county officials, community leaders, and community members during the Tidal Back River SWAP.

Community outreach is an important part of the success of improving water quality in our communities and Parsons Brinckerhoff continues to plan and implement new and innovative programs that raise public awareness.

[The authors would like to extend a special thank you to Larissa Sato, P.E. at the Honolulu office, for taking time to share her experiences.]

Kelley Moxley *is a Water Resources Engineer and part of the Water Technical Excellence Center in the Parsons Brinckerhoff Baltimore office. She has a BS in civil engineering with a focus on water resources from the University of Maryland. Her focal point at work includes watershed management studies, stream restoration, and hydrologic and hydraulic modeling.*

Stefany Wang *is a Water Resources Engineer and part of the Water Technical Excellence Center in the Parsons Brinckerhoff Baltimore office. She has a BS in civil engineering from Columbia University and is pursuing a MS in environmental engineering and science at Johns Hopkins University. Her main focus areas include watershed management studies, stream restoration, hydrologic and hydraulic modeling, and stormwater best management practices.*

Water Saving Design for the Abu Dhabi Metro System

by **Steven Lai**, Hong Kong, 852-2963-7625, lai.steven@pbworld.com; **Kenneth Chan**, Hong Kong, 852-2963-7634, chan.kenneth@pbworld.com; **Chris Ma**, Hong Kong, 852-2579-8533, ma.chris@pbworld.com; and **Jonathan Skittrall**, Abu Dhabi, +971-50-6668547, skittrallj@pbworld.com

Since 2010, the Hong Kong office of Parsons Brinckerhoff has designed the mechanical, electrical, and plumbing (MEP) services for the first metro system in Abu Dhabi. The metro system is part of the wider integrated public transport network (IPTN) which includes local and regional buses, light rail transit (LRT), bus rapid transit (BRT), and regional rail. This metro system includes a depot, ancillary buildings, underground and elevated stations, tunnels, and viaducts.

The project is currently in the preliminary design stage. During the design, various energy saving and water saving schemes were considered in order to achieve a sustainable metro system. This paper presents the various designs considered to recycle, reuse, and reduce water use. They include: re-cycling of condensate water from air-conditioning systems, use of water saving fixtures, and high efficiency irrigation technology solutions.

Condensate Water Recycling Installation

The condensate water discharges from air handling units (AHU) and fan coil units (FCU) generally contain small amounts of debris or pollutants and can be recycled to be used for floor cleaning, cooling tower make-up water, or irrigation. A condensate water recycling installation is primarily composed of:

- condensate water collection pipework;
- a condensate water storage tank; and
- a water disinfection plant and distribution pipework.

The condensate water flows through the condensate water pipe and is collected in a storage tank by gravity. The condensate water storage tank is usually made of reinforced concrete or fiberglass. The storage tank can be sized based on the recycled water consumption per day. The recommended standard of recycled condensate water quality is shown in Table 1. As an example, the pH value of condensate water should be between pH 6 and pH 9.

Parameter	Recommended Level
pH	6 - 9
Turbidity (NTU)	Less than 2
Biochemical Oxygen Demand BOD5 (mg/L)	Less than 10
Residual Chlorine (mg/L)	More than 1
Fecal Coliform (count/L)	0
(Source of reference: Design Guideline for Grey Water recycling installation, Architectural Services Department, HKSAR, 2008)	

Table 1 – Recommended Standard of Recycled Condensate Water Quality

In order to achieve this standard, an activated carbon filter and an ultraviolet (UV) light disinfection installation are required. Activated carbon filters can remove dissolved organics and the filter media can be cleaned and reused. The filter will operate continuously with an automatic backwash upon reaching a differential pressure of a pre-set value across the media bed or after a pre-set period.

Disinfection by UV light irradiation is used for water purification, sewage treatment, protection of food and beverages, and many other disinfection and sterilization processes. UV light disinfects faster than chlorine and does not require chemical storage. However, the recycled condensate water should be used immediately after UV light disinfection. It is recommended that a power meter and a water meter be provided to record the power consumption and the recycled water generated for monitoring. A typical schematic diagram for a condensate water recycling installation is shown in Figure 1.

Use of water saving fixtures

Besides recycling and reusing wastewater, another way to save precious water resources is to reduce water consumption. In this metro system design project, water saving fixtures were incorporated in all metro facilities to enhance the water efficiency of the system. Water-efficient applications require an initial investment, but this investment is paid back in the long-term. Some of the water saving fixtures incorporated in the design included:

- Waterless urinals - Waterless urinals look similar to regular urinals but connect to standard drainpipes and do not require incoming water for flushing proposes. All water associated with the flushing process is eliminated. The working principle of a waterless urinal is gravity; when urine enters the urinal, it passes through a sealant to the building drainage system by gravity. The sealant or liquid odor barrier has a specific gravity less than water and, because of this low gravity, urine and its associated gases cannot rise through the barrier.

- Low-flow showerheads and faucets – Low-flow shower head and faucets are water efficient and consume a lesser amount of water than normal fixtures. There are two types of low flow showerheads/faucets—aerating and non-aerating. Aerating types mix air into the water in order to maintain a constant pressure while using less water. The water flow is reduced. Non-aerating types use pulses to keep the stream strong while maintaining a constant temperature. A maximum 30% of water could be reduced by applying low-flow showerheads/faucets.

High efficiency irrigation technology

The metro project also included a number of landscaped areas which provided shading from the sun and improved the aesthetic and environmental quality of the area, especially the depot area. To reduce the water consumption for this site, high efficiency irrigation technology and design was proposed as follows:

- Solar-powered irrigation system - A solar-powered-automatic irrigation control system is a low-maintenance and environmentally friendly design choice. It incorporates evapotranspiration (ET) data provided by a solar powered wireless weather station which can monitor and measure rainfall, humidity, wind speed, radiation, and temperature. This irrigation control system is programmed to monitor, control, and adjust irrigation schedules for several zones as far away as 100m through the data received from the weather station on the site condition.

- Dripline systems – Driplines are polyethylene (PE) tubing with preinserted emitters spaced at specified intervals, that convey drops of water from the tubing to the soil. Each dripline emitter has a floating silicon diaphragm, which provides a pressure compensating effect. The special mould design of the emitter inlet chamber together with the pressure compensating effect form a check-valve. This check-valve emits water drops at a specific rate, and stops emitting water when the water pressure is kept at or below 1.5 psi. This feature protects the dripline from siphoning small soil particles or debris to the drippers, making it ideal for both subsurface and on-grade drip installations. A water meter is recommended for water consumption monitoring.

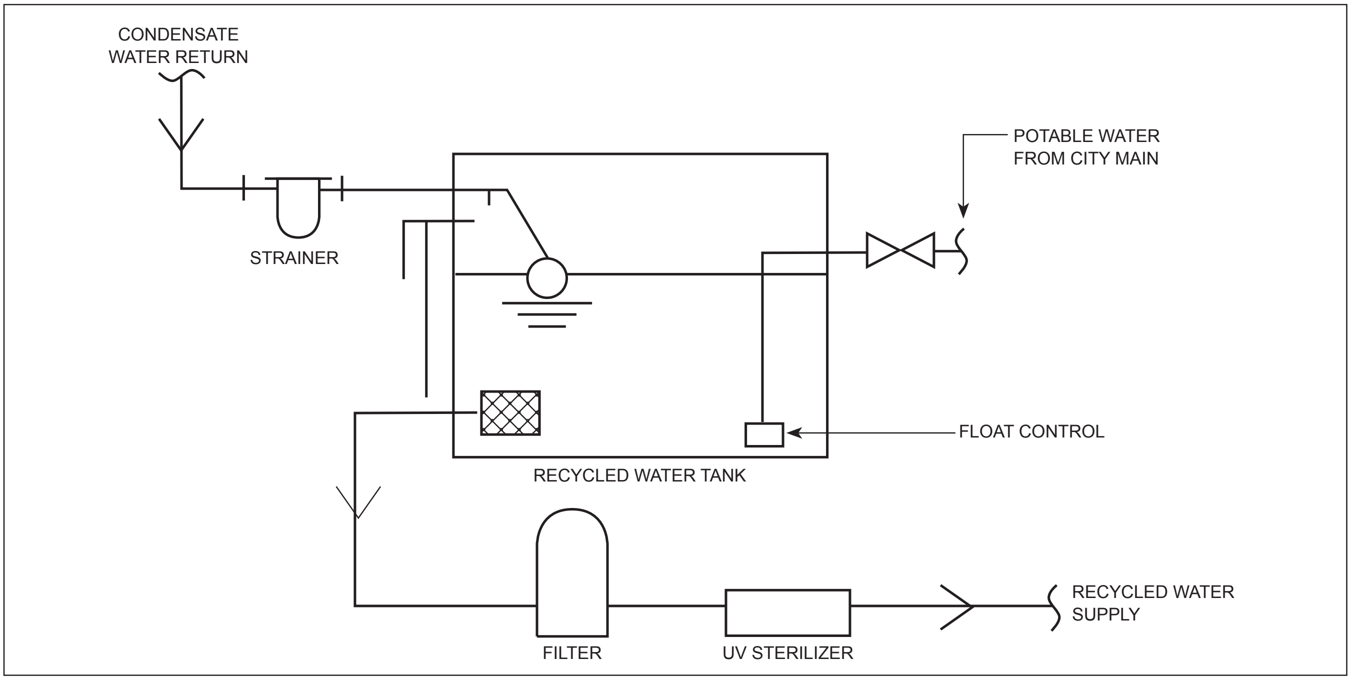


Figure 1 – Typical schematic diagram of a condensate water recycling installation

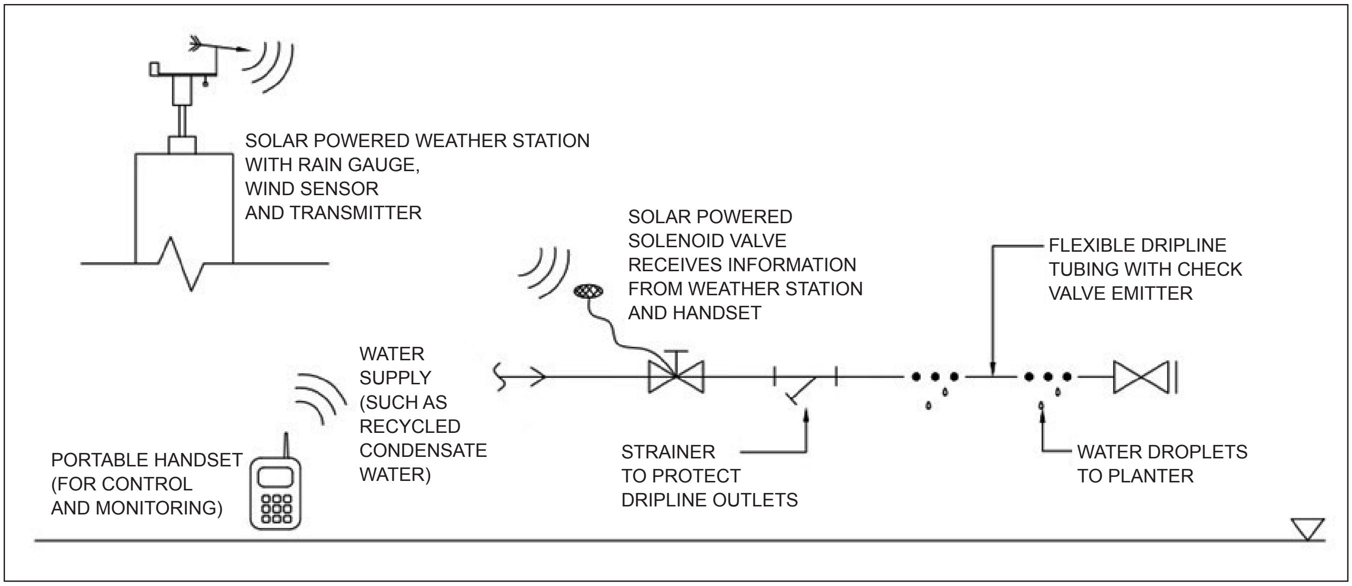


Figure 2 – Typical solar-powered wireless automatic control dripline irrigation installation

A schematic diagram of a typical solar wireless automatic irrigation control system is shown in Figure 2. This technology is well-established in the industry. Water is saved by monitoring soil conditions instead of by timer control. In a recently completed project in Hong Kong, where the rainy season is from April to September, an average of over 70% of water was saved by this technology. There is also a reduction in power usage and control wiring.

Water is among our most precious resources. In the Abu Dhabi metro project, Parsons Brinckerhoff has been able to implement designs that increase water efficiency, thereby reinforcing our commitment to provide our clients with sustainable solutions.

Steven Lai *is a Mechanical Engineer and Senior Professional Associate at Parsons Brinckerhoff. With 24 years of experience, he has served as lead engineer on many tunnel ventilation system and environmental control system related projects. He is MEP Project Manager in the Hong Kong office for the Abu Dhabi Metro Study – Stages 1 & 2.*

Kenneth Chan *is a Mechanical Engineer and a Professional Associate (water and wastewater) at Parsons Brinckerhoff. He is a Chartered Environmentalist (UK) and also a BEAM Professional in HK. With 19 years of experience, he has served as lead engineer on many plumbing, drainage system, and sustainable design related projects. He is the PD and FS lead engineer for Abu Dhabi Metro Study - Stages 1 & 2.*

Chris Ma *is a Mechanical Engineer who participates in road tunnel and metro projects and has experience with building information modeling (BIM), Subway Environment Simulation (SES), and Primavera P6 on projects. He is assistant engineer for Abu Dhabi Metro - Stage 2.*

Jonathan Skittrall *is a Lead Civil Engineer with 17 years' experience with Parsons Brinckerhoff. He is based in the United Arab Emirates and serves as coordinator between the design teams and the client on the Abu Dhabi Metro Project.*

Operational and Financial Challenges of Procuring Water Treatment Plants for Remote Communities

by **Susan Kizito**, Brisbane, AUS, +61 7 38546644, kizitos@pbworld.com

Introduction

The procurement, installation, and operation of water treatment plants (WTPs) present significantly greater technological, operational, and financial challenges in small remote communities than in urban communities. These challenges include, but are not limited to: residents' skills and capabilities to maintain and monitor the plant, distances to external service providers, limited choices of water sources, the condition of existing infrastructure, and the required functionality of the water treatment plant. Some of these key challenges are addressed in this article.

The bridge between key challenges and successfully installing and operating WTPs in remote communities is also addressed in this article and includes the following:

- Understanding of site challenges by the client and WTP supplier;
- Modifying the WTP to meet operational requirements of the community; and
- Adequate financial investment.

Due to the small size of remote communities, packaged WTPs are usually preferred. Packaged WTPs are factory-assembled water treatment plants and generally have small footprints. They are of suitable size for containerisation or housing in small enclosed buildings and produce the same quality of treated water as the larger water treatment plants used in urban areas. These plants can be automated or manually operated, depending on operational requirements, and are transportable to the required location.

Key Challenges

Water treatment plant functionality – WTPs available on the market can generally meet the required water quality objectives; however, these plants are not designed to meet the rigours of being operated in remote communities. Frequent plant attendance is often required to monitor performance and in remote communities there are typically no qualified personnel to provide this support. Therefore, external management of the operation and maintenance of the WTP and scheduled attendance are required. It is necessary that modifications to the overall functionality of the WTP be made which enable it to function unattended for longer periods of time and also enable remote monitoring and operation by external parties. Typical modifications include duty/standby pump arrangements, remote monitoring and operation capability, and automated or self-cleaning capability.

Under the Remote Area Essential Services Program (RAESP) run by the Department of Housing, 91 indigenous Aboriginal communities in remote Western Australia are serviced in the delivery of water, wastewater, and power services by regional service providers who attend to the communities on a six week cycle. Parsons Brinckerhoff manages essential services to these communities on behalf of RAESP (see Figure 1).

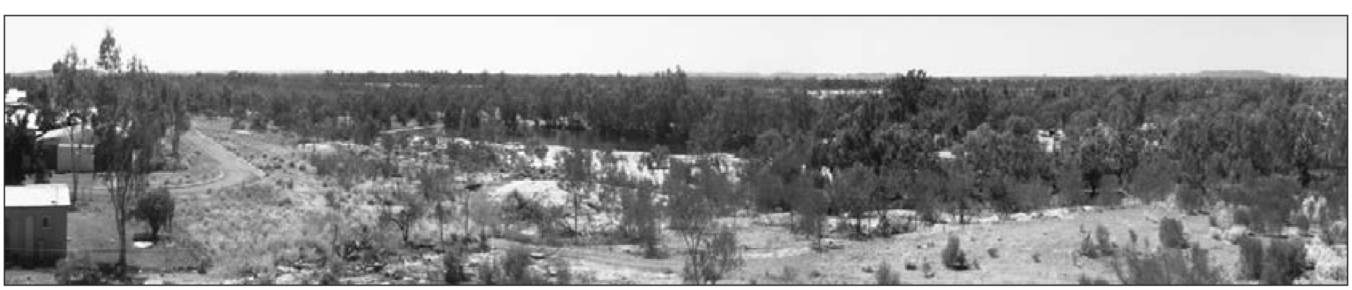


Figure 1 – Typical remote community site for a WTP installation

Financial investment – Final project costs for the installation of WTPs in remote communities generally tend to be higher than the projected project budget. The key reason for this is the lack of understanding of the site constraints by the supplier and the inability to assess the detailed design drawings for the proposed packaged WTP prior to the award of the contract.

Distances to external services – A key challenge is the distance to the nearest large town from which skilled personnel and plant equipment can be sourced. This distance ranges from hundreds to thousands of kilometres (see Figure 2). The major towns in the Kimberley and Pilbara regions are Broome and Port Hedland, respectively, while along the coastline Kalgoorlie is the main town for the Goldfield region. Installation and operation of a WTP in these communities results in significant travel and labour costs of generally not less than AUD$1,000 (US$905) per visit to the community for attendance by remote service providers.

The Bridge to Success

Understanding of site challenges

A requirement for the successful procurement, installation, and operation of the WTP is the appreciation and understanding of site constraints by the client, plant operators, and WTP supplier. Contract or project award is generally undertaken through a tendering process. This process involves the provision of a proposal with a general layout and process drawings of the plant. Upon award of the contract, the preferred WTP supplier provides detailed drawings of the plant which indicate the suppliers' understanding and appreciation of the site constraints. This leads, in many cases, to a need for modification or upgrade of the plant design in order to meet these constraints, which subsequently leads to a variation of the supplier quote. To mitigate or minimise this, site visits and meetings between the client

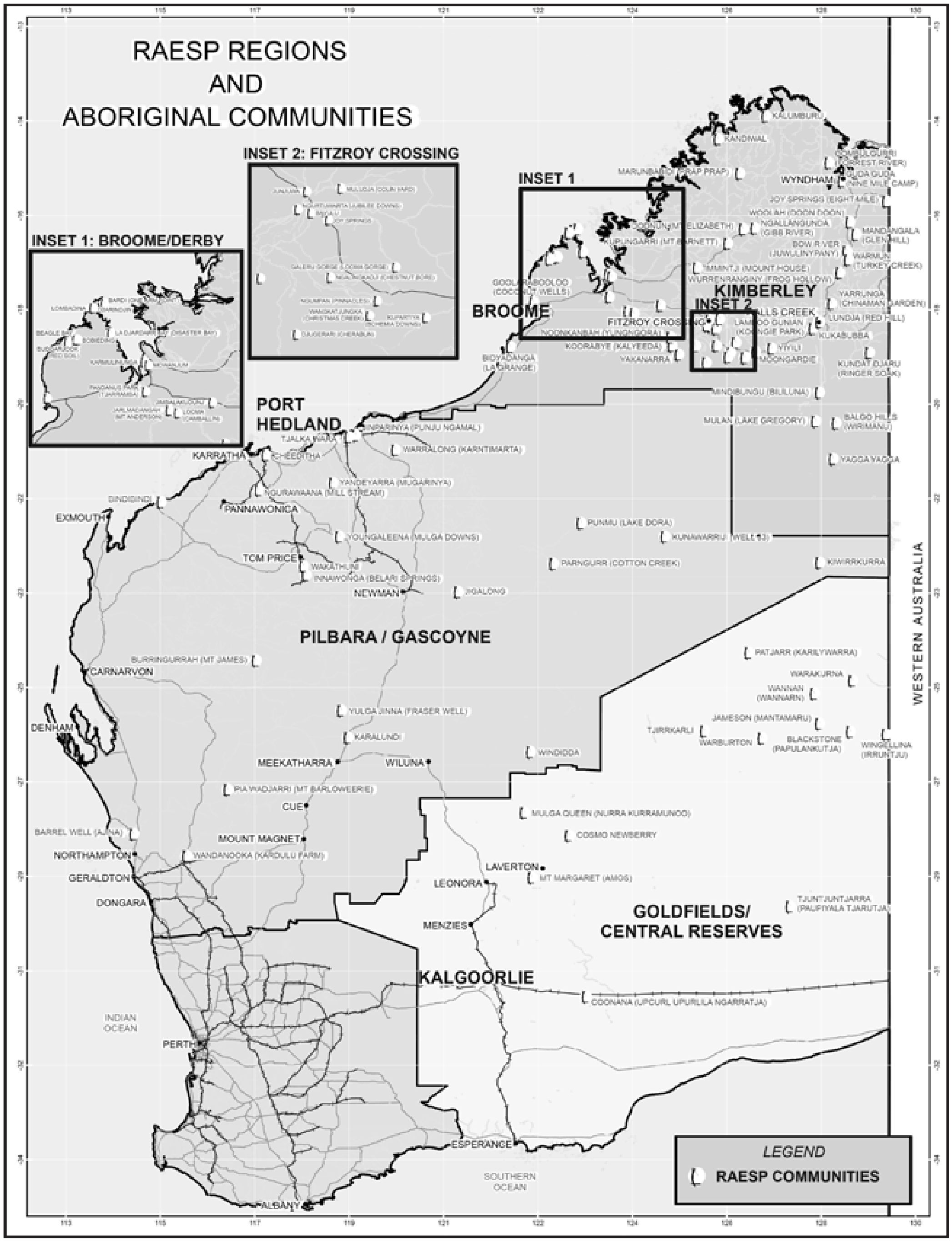


Figure 2 – Remote Area Essential Services Program (RAESP) coverage

(or client's representative) and potential WTP suppliers prior to submission of a tender response will provide an understanding of the site constraints and the required functionality of the plant.

Modifications or add-ons to WTP – Modifications or add-ons to the WTP are in most instances necessary to meet the site and operational requirements. Modifications and add-ons can include: duty standby pumps, remote monitoring capability, temperature sensors, etc. These inclusions enable remote monitoring and operation of the WTP, rectification of plant failures in some instances, purchase of required plant parts prior to the servicing and maintenance of the WTP, and continuous water supply to the community with built-in redundancy.

Project cost – Understanding all the project costs associated with the installation of a packaged WTP requires a detailed evaluation of all associated costs ranging from the ancillary infrastructure required to make the plant operational, delivery and travel costs both in the installation and operational phase, operating costs, and site preparation costs. A detailed feasibility study should be performed prior to the commencement of the tender phase. Pre-design of the WTP by the client (or client's representative) will benefit the overall tender phase and engagement of the preferred WTP supplier. Financial investment in the pre-tender phase is important and beneficial to both the client and supplier as the likelihood of increased project costs is minimised.

Conclusion

The procurement, installation, and operation of a packaged WTP in remote communities present more challenges than similar installations in urban communities. Most available WTPs are not suited to meet operational requirements in remote communities, especially where there is a lack of technical personnel and travel distances to the community are lengthy. The key factors mentioned in this article need to be considered and undertaken prior to the release of a tender or request for quote. This will require the commitment of all involved parties in order to negotiate the various challenges brought about by this process, and ultimately the successful installation and operation of the WTP in remote communities.

This success is demonstrated by an ion exchange WTP recently installed in a remote Pilbara community in Western Australia. (see "Ion Exchange: A Viable Water Treatment Alternative to Membranes," by Gary Thorne and Joel Segal in this *Network* issue) Add-ons to the plant have enabled the six-week maintenance cycle by the regional service provider to continue without ongoing plant operator attendance during this period and also enabled the remote monitoring of the plant.

Susan Kizito *is a Senior Water Engineer at Parsons Brinckerhoff and Water Quality Manager for the Remote Area Essential Services Program which services 91 remote Aboriginal communities in Western Australia. She has experience in water quality, water treatment, wastewater, and water resource management.*

Arsenic Removal Water Treatment System Design for a Remote Community

by **Mei Yau**, Perth, AUS, +61 8 92163671, yaum@pbworld.com

Parsons Brinckerhoff manages essential services to 91 remote Aboriginal communities on behalf of the Western Australian Department of Housing through the Remote Area Essential Services Program (RAESP). The water treatment team, within Parsons Brinckerhoff's Perth office, works to supply the communities with drinking water that complies with the Australian Drinking Water Guideline (ADWG) standards.

This article details the criteria for the design of a drinking water treatment plant in a remote indigenous community that has three water supply bores. Two low-yielding bores supply the community with potable water. The third high-yielding water bore was taken offline due to elevated levels of arsenic, found to be as high as 0.02 mg/L, which is double the 0.01 mg/L limit the ADWG recommends for health reasons. The RAESP sought to lower the arsenic level and bring the third bore back online to satisfy the community's growing demand for water.

Background information and design criteria

Arsenic (As), a naturally occurring element, is introduced into water when minerals and ores are dissolved. Arsenic contamination of groundwater is a global issue, with severe and documented cases reported in Asia and South America. When arsenic dissolves in water it forms oxyanions: trivalent arsenite As(III) under reducing conditions or pentavalent arsenate As(V) under oxidising conditions. The selection of a suitable arsenic treatment technology is dependent on the system design meeting the following criteria:

- Has the ability to lower the arsenic level to the ADWG limit of 0.01 mg/L;
- Requires minimal human intervention (regional service providers routinely visit remote communities every six weeks to maintain and monitor the system);
- Requires minimal power consumption and footprint;
- Must be robust enough to withstand the harsh conditions of the Western Australia Kimberley region;
- Requires minimal pre-treatment;
- Produces no waste stream; and
- Is cost effective to construct, maintain, and operate.

Treatment options

With all the above criteria to be considered, the technology options that were investigated were: coagulation and precipitation, reverse osmosis, ion exchange, in situ groundwater treatment, and adsorption.

Coagulation and precipitation

The process of coagulation and precipitation involves adding a coagulant to the drinking water, then clarifying and filtering it. Coagulation has been shown to be less efficient for removing arsenite than for removing arsenate. Chlorine, ozone, chlorine dioxide, or potassium permanganate can be added before coagulation to oxidise arsenite and convert it to arsenate. The addition of coagulant optimisation and redox control for oxidation requires an intensive control system. This increases operating and maintenance costs and, as the plant is unmanned for six week periods, increases the potential for plant failure. Maintaining such a system was considered too complex and requires a larger plant footprint. The process of removal of arsenic by coagulation and filtration was therefore not explored further.

Reverse osmosis

Reverse osmosis (RO) removes arsenic and other impurities from drinking water by forcing water through a membrane at high pressure, leaving the contaminants and rejected water on one side of the membrane and treated water on the other. Although a valid treatment option, RO was quickly abandoned as a treatment method due to silica-based fouling issues and the rejected water (35% of the influent water) becoming a waste stream that contains much higher levels of arsenic (approximately 0.05 mg/L). This waste stream would need to be contained, complicating the design and creating an environmental sustainability problem and an increase in operating costs.

Ion exchange

Pentavalent arsenic is present in drinking water as dihydrogen arsenate (H_2AsO_4-) and monohydrogen arsenate ($HAsO_4^{2-}$), so it is possible to remove arsenic by anion exchange. When arsenic-laden water passes through a strong base anion resin, arsenate ions are exchanged for other anions on the resin.

This process was thoroughly investigated, as it is much simpler than either coagulation or reverse osmosis. However, using ion exchange creates some problems—the resins require regeneration, they produce a wastewater stream, and arsenic can be released back into the environment. The process would require pre-treatment to remove organics, suspended solids, and other contaminants that would foul the resins and decrease their effectiveness. Therefore, ion exchange was not explored further[1].

In situ groundwater plant

Investigations to find a more suitable treatment process revealed Dr. Bhaskar Sen Gupta's subterranean arsenic removal (SAR) technology[2]. The SAR process takes the oxidation and filtration process used in aboveground water treatment plants and transfers it underground, into the aquifer.

Groundwater is extracted into a tank at ground level, aerated and re-injected into the water supply bore. Aeration causes the oxidation of arsenite to arsenate, ferrous to ferric (Fe^{3+}) and manganese (II) (Mn^{2+}) to manganese (IV) (Mn^{4+}). This creates an arsenate co-precipitated with the Fe^{3+} and, to a lesser extent, Mn^{4+} precipitates reducing the content of arsenic in the extracted bore water. The water is then filtered by the surrounding sand, which removes the contaminants. However, when Dr. Gupta reviewed the quality of the water at the remote community, he advised that the combined levels of Fe^{3+} and Mn^{4+} were too low to create a stable reaction in the water supply. This process option was also eliminated.

Adsorption

In the adsorption process, arsenic ions adhere to a solid surface and are extracted from the water. This surface is typically a metallic-based granular media held in a pressure vessel. Arsenic-laden water travels through the vessel and makes contact with the media. Arsenic is adsorbed onto the media, and the water leaving the pressure vessel has considerably lower arsenic levels. The adsorption process, unlike the ion exchange process, does not release an anion in place of the arsenic, leaving no risk of increasing anion levels in the water. Furthermore, the adsorption process satisfied all aspects of the design criteria (as mentioned above) with the most important emphasis placed on its ability to produce a non-contaminated waste stream that will not require further treatment prior to disposal.

DOW Chemical Company was approached to provide titanium-based granular media that would meet the requirements for improving the remote community's water quality, and was asked to prepare an estimation of projected effluent quality based on a 12-month media replacement cycle. The company recommended ADSORBSIA™ AS600 media. ADSORBSIA™ is a titanium oxide adsorbent that has a strong affinity for arsenic, lead, and other heavy metals. It is designed to be non-regenerative, needs less maintenance, and is therefore ideal for a remote community. Once exhausted, the adsorption media are disposed at an approved landfill only after having been tested and approved as per the toxicity characteristic leaching procedure (TCLP) extraction protocol of the US Environmental Protection Agency (EPA). The TCLP predicts if hazardous components of a waste are likely to leach out and become a threat to public health or the environment.

Final system design and construction

In the final design (Figure 1), an adsorption media pressure vessel was installed in a 3.1m (L) x 2.44m (W) x 2.59m (H) shipping container (see Figures 2 and 3) to minimise the footprint and protect the plant from the harsh conditions of the region. The adsorption media system requires backwashing to remove particulates on a quarterly basis; backwashing is initiated manually. The backwash flow rate is dependent on the water temperature (see Figure 4) with a bed expansion of 35% during backwash. The backwash is suitable for disposal to leach drains as it will contain little to no arsenic contaminants. The system design uses a 12-month

[1]For further ion exchange technology detail, read "Ion Exchange: A Viable Alternative to Membranes" by Gary Thorne and Joel Segal in this issue of Network.

[2]For further SAR technology detail: http://www.insituarsenic.org/

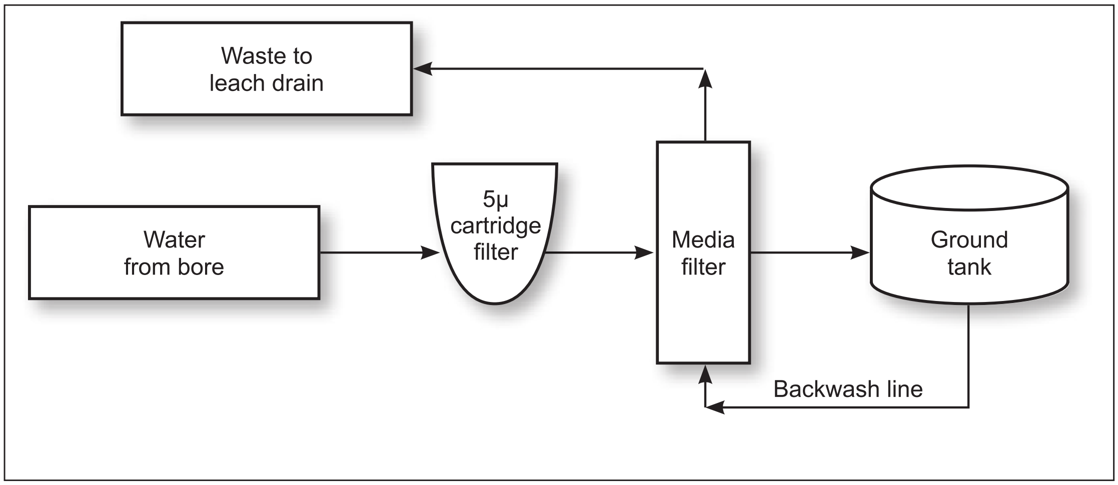


Figure 1 – Arsenic-removal process flow diagram

Figure 2 – Adsorption media vessel was installed in a 3.1m (L) x 2.44m (W) x 2.59m (H) shipping container

Figure 3 – Arsenic water treatment system constructed on site installed in the 3.1m (L) x 2.44m (W) x 2.59m (H) shipping container

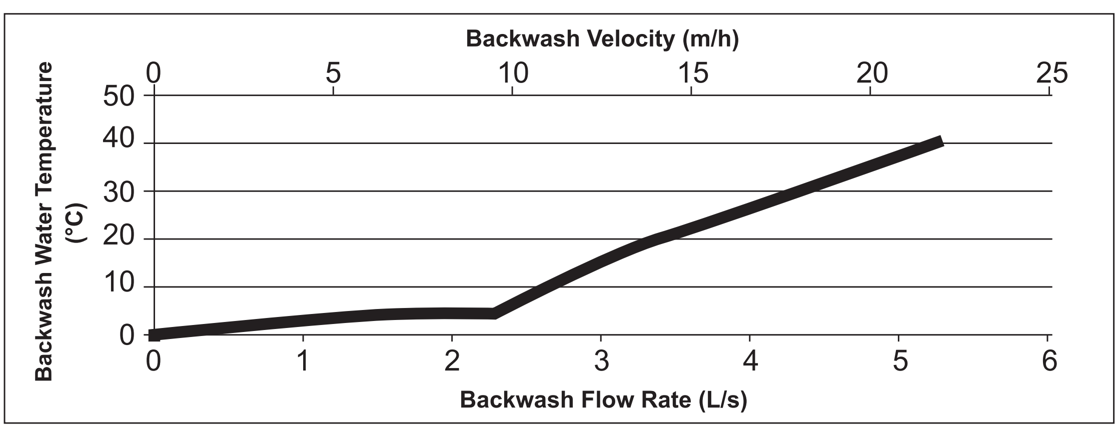


Figure 4 – ADSORBSIA™ AS600 media backwash flow rate relative to temperature of backwash water

media replacement cycle; at the end of the cycle, the adsorption media are removed through the top-entry access and are tested and disposed of via an approved landfill site.

An adjustable differential pressure switch is installed over the arsenic media bed pressure vessel and the 5 micron particulate cartridge filter, and is set to notify remote service providers (RSP), via a telemetry connection, of the need to wash or change the adsorption media and cartridge filters on their next routine visit (every six weeks).

Conclusion

Innovative solutions are needed for the design of a system suitable for treating arsenic-contaminated water in a remote Western Australia community. The system needs to be sustainable, simple, effective, and have minimal maintenance and operating costs.

Treatment options investigated by Parsons Brinckerhoff included coagulation and precipitation, reverse osmosis, ion exchange, an in situ groundwater treatment plant, and an adsorption process system. The adsorption process system, using the DOW Chemical ADSORBSIA™ AS600 titanium oxide media, provided the best solution to a complex problem in this remote community and also satisfied the design criteria that was initially established for the selection of a specific arsenic removal technology. The only regular consumable is the 5 µm cartridge filter, which removes particulates to increase the adsorption unit's run cycles.

The arsenic-removal plant was installed and commissioned in September 2012. Because the contaminated water supply bore remained offline for a prolonged period of time, arsenic levels in the bore water have been low. However, according to water quality testing, there is a gradual increase in arsenic levels in the water supply bores over time due to continuous extraction. Sample results to date (see Figure 5) show that the plant has been able to lower arsenic levels to ADWG-compliant potable water.

Date	*Pre media vessel Arsenic level (mg/L)*	*Post media vessel Arsenic level (mg/L)*
28/09/2012	*0.001*	*<0.001*
11/12/2012	*0.003*	*<0.001*
05/02/2013	*0.001*	*<0.001*
07/04/2013	*0.002*	*<0.001*

Figure 5 – Sample results

The water treatment unit for removing arsenic is only one example of Parsons Brinckerhoff's use of options analysis to select the most suitable water treatment process for remote communities in Western Australia. Some of the other drinking water treatment systems designed by Parsons Brinckerhoff include nitrate removal, iron removal, pH adjustment, and fluoride reduction.

Mei Yau *is a Water and Process Engineer in the Perth office of Parsons Brinckerhoff in Western Australia. She has a chemical engineering degree and has worked in design and review for the treatment of problematic drinking water in remote communities of Western Australia. These processes include: arsenic removal, nitrate removal, iron removal, and fluoride reduction. She has an interest in utilising new technology to design environmentally sustainable treatment systems.*

Ion Exchange: A Viable Water Treatment Alternative to Membranes

by **Gary Thorne**, Perth, AUS, +61 8 92163680, thorneg@pbworld.com; and
Joel Segal, Brisbane, AUS, joelsegal3@gmail.com

Five decades ago, ion exchange using charged resins was one of two processes used in the water industry for water treatment. The ion exchange (IX) process involves 'swapping' an undesirable dissolved salt – for example, arsenic, calcium, or radium – for a more benign ion such as sodium. In the late 1980s, membranes used in reverse osmosis (RO) were becoming the favoured process, but IX never disappeared. IX evolved from a chemical-based regeneration process to one that still used chemicals but also used positive and negative electrical charges to regenerate the resin.

Parsons Brinckerhoff has used electro-deionisation in several power station designs. More recently Parsons Brinckerhoff has started to look at selective resins for treating specific water contaminants in remote communities and acid mine wastes.

Water Treatment in Remote Communities

One of the key advantages IX and adsorption processes (see "Arsenic Removal Water Treatment System Design for a Remote Community" by Mei Yau in this Network issue) have over RO in remote areas is the waste volumes of water produced. For every volume of water treated by RO, anywhere from 10% to 50% of that amount is rejected as a concentrated brine stream. With IX, only the spent regenerant chemical and some of the rinse water are wasted, which is typically only 2% to 4%. This preserves much-needed water in remote, arid areas where a consistent water supply is often a challenge.

Since 2005, Parsons Brinckerhoff has managed the Remote Areas Essential Services Program (RAESP) on behalf of the Department of Housing in Western Australia. A recent project involved the treatment of a communal water source that had high nitrate levels. The presence of high silica levels restricted the water recovery ratio of an RO system to only 50% to 60%, so alternative processes such as nitrate-selective IX resin were considered because of the reduced volume of water wasted and the improved nitrate removal over a six-week period. The advantages for this project were the following:

- IX waste volume could be sent to an existing sewage evaporation pond, whereas an additional evaporation pond area would be required for the membrane processes (RO and EDR) waste volume (see Table 1);
- In addition to the wastewater volume, once evaporated, the membranes produce twice the dried weight of salts, which also has to be disposed (see Table 2);
- Reduced power costs (see Table 3);
- Chemical regenerant is a salt solution (NaCl), whereas the membrane (RO and EDR) systems required a specialty antiscalant and other chemicals, such as HCl, to be provided on a regular basis to clean the membranes (see Table 4); and
- Longer resin life compared to membrane life.

The same principle of selective resins was applied to the removal of uranium from a remote Australian community's water source, and has reliably produced quality drinking water since its installation nearly two years ago.

Process	Produced Volume per Day (m^3)	Waste Volume per Day (m^3)	Process Efficiency	Nitrate Raw (mg/l)	Nitrate Predicted minimum residual (mg/l)	Capital Cost
RO	550 (145,200 gal)	366 (96,624 gal)	60%	85 -120	40	$230k
EDR[1]	550 (145,200 gal)	61 (16,104 gal)	90%	85 -120	40	$600k
IX	550 (145,200 gal)	17 (4,488 gal)	97%	85 -120	8	$285k

Table 1 – Waste volumes of various water treatment processes

[1]EDR is electrodialysis reversal, a water desalination membrane process that has been commercially used since the early 1960s and allows silica to pass through the process without scaling

Process	Dried Waste Stream (tonnes/yr)	Prediction Basis
RO	224	Based on 100 mg/l in permeate
EDR	222	Based on 9970 mg/l in waste stream
IX	108	Salt consumption for the year.

Table 2 – Dried waste stream of water treatment processes

Process	Power Required	Annual Power Operating Cost
RO	220kWh	$12,045.00
EDR	25kWh	$1,368.75
IX	5kWh	$273.75

Table 3 – Power costs of water treatment processes

Process	Annual Process Chemical Cost	CIP and Maintenance every 6 weeks (Hrs)	CIP Cost per year
RO	$36,500.00	10.00	$13,000.00
EDR	$10,567.91	6.00	$7,800.00
IX*	$27,101.25	1.00	$150.00

*Based on the maximum NaCl cost of $250/tonne

Table 4 – Chemical and maintenance costs of water treatment processes

Water Treatment in the Mining Industry

Another field in which Parsons Brinckerhoff has specified IX systems is in the mining industry for acid mine drainage. Two Asian copper mine projects required large volumes of river water to be pumped for use in the mine operations. If standard dam management principles were applied, the extracted water would no longer be available to communities downstream whose water demand was already near capacity in the dry season. An additional issue facing the mines was the extensive wet season, which removes the possibility of using solar evaporation and increases the potential of flooding to waste storage dams.

Treating the waste stream for compliance with the local environmental protection requirements could be easily achieved, but in each case the mine owner recognised that having a sound environmental approach was the only way forward. It was, therefore, imperative that the project did not reduce water flow or quality to downstream users. The Australia and New Zealand Environment and Conservation Council (ANZECC) water quality guidelines were applied to bring the discharge limits back to receiving water quality levels. This requirement promoted the recycling of the tailings dam and drainage water, while stringent discharge water quality targets fostered the need for a high level of water treatment to achieve combined treated water flows of up to 172 ML/day.

An integrated, phased water treatment approach was identified as the most cost-effective treatment strategy. After extensive market evaluation, there were no similar plants operating in Australia, so due diligence audits of available treatment processes (in the US and China) were undertaken. The findings were added to the Parsons Brinckerhoff "bow tie" risk-weighted net present value (NPV) options analysis methodology, which is based on ISO 31000 Risk Management technique B.21 (see Figure 1). The process details the various pathways to potential loss, including environmental damage, and those controls critical to the prevention and mitigation of loss.

Two viable outcomes formed a common approach to the pre-treatment of metal precipitation which is followed by the RO or IX process to remove sulfates.

- Reverse osmosis with conventional softening through the metal precipitation process typically achieved a 65% recovery ratio and provided permeate (product water) with a composition that could negatively impact the receiving ecosystem. Remineralisation to restore the hardness, alkalinity, and pH to background levels was a requirement. Due to the humidity and rainy seasons, evaporation ponds were not feasible, and so the RO waste concentrate stream would require further treatment through brine concentration and crystallisation.
- The IX process would regenerate on a 12-hour cycle and provide approximately 90% efficiency. The IX process can efficiently operate on gypsum-saturated waters to achieve final sulfate concentrations of 200 to 500 ppm,

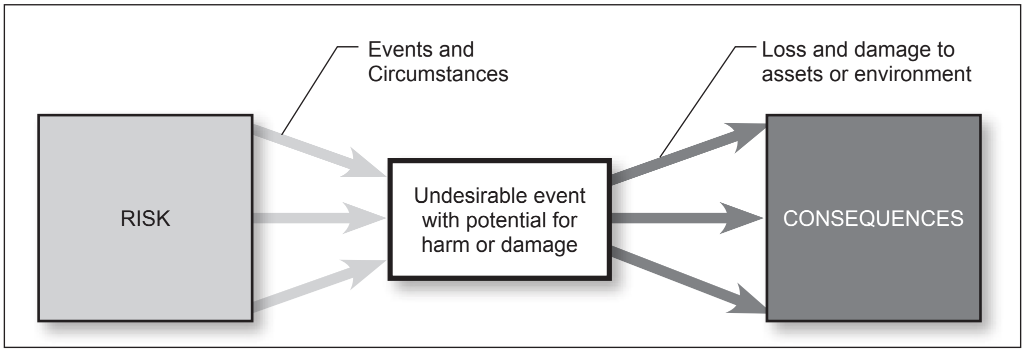


Figure 1 – An example of Bow Tie Risk analysis

while producing a pure gypsum ($CaSO_4$) by-product. The IX process removes calcium and sulfate from wastewater in order to achieve effluent compliance with sulfate discharge limits, which has the added advantage of reducing final effluent total dissolved salt (TDS) concentration. The cation and anion resins are regenerated using sulfuric acid and lime, respectively, in both cases generating gypsum, which is precipitated using a seed. The gypsum by-product in its solid form can potentially be reused.

The IX waste stream is dewatered using a plate and frame membrane press, eliminating the need for crystallisation. The press filtrate is returned to the head of the treatment stream and the pure, solid gypsum can be sold to the building material industry or used in soil augmentation.

When comparing the two processes, the benefits of the IX system are:

- Capital cost is about 40% less, as the concentration/crystallisation stage was not needed;
- Operational costs are about 50% less (mostly due to the greatly reduced power demand); and
- There is approximately 80% less CO_2 emissions due to the much lower power requirements.

This initiative not only transformed a potential environmental threat into a sound environmental opportunity, but also demonstrates the feasibility of large-scale alternatives to current wastewater management strategies.

Developing a Water Treatment Strategy

The current water industry practice is often to focus on membrane technologies, which have taken a large share of the desalination market. Particularly for brackish water, membranes have completely superseded IX as the technology of choice. Today IX is making a comeback for the treatment of natural, surface, or deep well water. Parsons Brinckerhoff is assisting an IX technology company to develop a process to treat coal seam gas water and brackish water, two major treatment challenges currently facing the Australian mining industry. A member of the Parsons Brinckerhoff treatment team developed the tri-bed desalination process with the assistance of resin manufacturer Rohm and Haas, and the first working process was installed and operating in the 1980s.

The introduction of improved weak base anion and weak acid cation resins, which result in lower regeneration costs and higher exchange efficiencies, means the process can be a cost effective alternative to membrane systems on lower salinity brackish water. The original tri-bed process was a three-pass system:

1. Alkalisation - Resin is in the bicarbonate form, which will remove the associated anions (chlorides, sulfates, nitrates, etc.). The final products from the unit are calcium bicarbonate, magnesium bicarbonate, etc.
2. De-alkalisation - Resin is in the hydrogen form. Cations (calcium, magnesium, sodium, etc.) are taken up by the resin, with only water and carbon dioxide leaving the unit.
3. Carbonation - Weak base anion resin in the hydroxyl form takes up the carbon dioxide to convert the resin to the bicarbonate form, with desalinated water leaving the treatment plant.

Regeneration of the first two units is carried out in external regeneration columns with sulfuric acid and lime, while the final stage resin is transferred to the first vessel to be utilised for its bicarbonate form. Testing has shown the process can be adapted to operate efficiently over a range of brackish water salinities (up to around 6000 ppm).

Costing studies have been conducted by various companies to help clients determine under what scenarios IX or RO is the more appropriate and cost-effective choice. However, rather than viewing them as competing technologies, we are seeing a move towards viewing them as technologies with overlapping, but also individual, niche markets as evidenced by the highly selective nature of certain resins. Moreover, they are more commonly used as complementary technologies, where IX reduces the scaling potential on high salinity water or polishes the membrane permeate, to achieve a difficult water quality target with minimal waste streams.

Gary Thorne *is a Principal Water and Process Engineer with over 35 years' experience in the consulting and contracting professions in developed and developing countries. His experience includes conceptual and detailed design, construction, commissioning, testing, and operation of a wide range of water, wastewater, and sludge treatment plants.*

Joel Segal *is a former Graduate Water & Process Engineer at Parsons Brinckerhoff. His experience is in water and wastewater treatment system design, with a particular focus on reverse osmosis and desalination systems and their applicability to the coal seam gas industry.*

Guidelines for Improving the Quality and Availability of Drinking Water in Iraq

by **Joanna Goodwin**, Bristol, UK, 0117 9339394, Joanna.goodwin@pbworld.com

Introduction

On 13 September 2011, the Iraqi government adopted important new guidelines to help improve the quality and availability of drinking water throughout Iraq. The guidelines were prepared by Parsons Brinckerhoff and represent a critical step forward in rebuilding the country's essential infrastructure after decades of turmoil. Importantly, the guidelines provide a starting point for a collaborative approach to the planning, implementation, and operation of reverse osmosis (RO) water treatment systems for the purpose of improving the supply of clean drinking water to the Iraqi population. Not only do the guidelines provide strategic and technical recommendations, but also appropriate use of the guidelines will enable all key stakeholders to be involved in the planning, implementation, and operation of RO water treatment systems, and hence promote long-term success of RO water treatment projects.

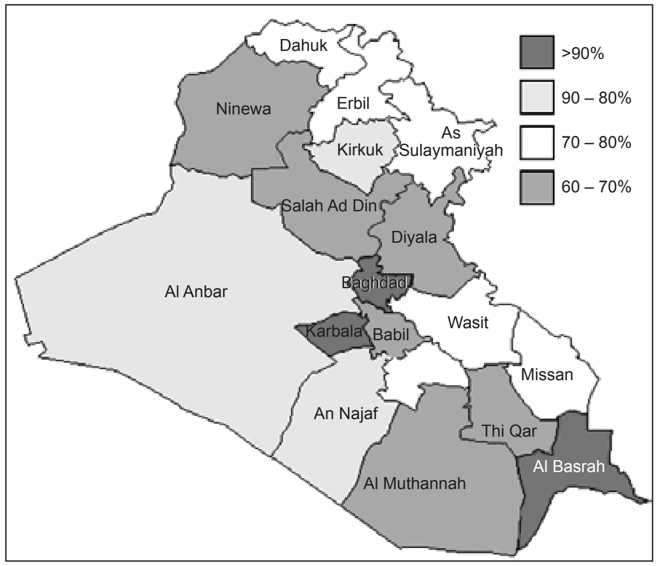


Figure 1 – Iran is composed of 18 governorates. This map shows the percentage of households connected to the public water supply system throughout Iraq (World Bank 2007)

Why were guidelines needed?

Numerous issues have previously undermined Iraq's water management systems and, over the past three decades, access to good quality drinking water in Iraq has deteriorated. A survey undertaken by the World Bank in 2007 identified that less than 70 percent of the population in some governorates of Iraq had access to a public water supply (see Figure 1). In rural areas, only 50 percent of the population surveyed had access to a public water supply network and 26 percent relied on a river or creek as their main water source.

The quality of drinking water is also considered to be poor. Treated drinking water samples analyzed by the Iraqi ministries in 2004 and 2005 indicated that approximately 40 percent of samples failed the Iraqi National Standards and World Health Organisation (WHO) guidelines for drinking water quality. The most prevalent water quality issues are typically associated with salinity, turbidity, and chemical and organic impurities.

Salinity varies considerably throughout Iraq. For water flow entering Iraq, salinity is typically in the region of 600 mg/l in the Euphrates River and 280 mg/l in the Tigris River. Downstream in the governorate of Al Basrah, salinity is reported to be as high as 6,000 mg/l. This is 10 times higher than the recommended maximum as stated in the WHO guidelines for drinking water quality.

The greatest contributor to increased salinity is the return flows from irrigation projects in Iraq and upstream of Iraq, in Turkey and Syria. Continued development in irrigated agriculture combined with predicted reductions in natural river flows are likely to exacerbate existing water quality issues.

Chemical and organic pollution is also a problem with Iraq's water resources. High chemical loading from pesticides and fertilizers used in agriculture are contained in return flows from irrigation systems. Poor sanitation and wastewater treatment facilities result in the discharge of untreated effluent to watercourses. Approximately 70 percent of Iraq's sewage discharge is currently untreated, and it is estimated that approximately one million tons of raw sewage are discharged into the rivers every day.

Insufficient availability of clean water poses a serious health risk to the Iraqi population. A study undertaken by the UN in 2010 suggested that waterborne diseases such as cholera and diarrhea are still present and widespread throughout Iraq due to polluted drinking water supplies and poor sanitation.

Infrastructure quality

One of the greatest challenges facing potable water supply in Iraq is the quality of existing infrastructure. The efficiency of the existing water supply systems is only approximately 30 percent of production, with water losses constituting approximately two-thirds of the water pumped and treated. Current potable water production capacity is estimated at 6.8 million cubic metres per day (equivalent to about 240 litres per person per day). However, if high losses through the supply systems are taken into account, the actual potable water supply is about 2.2 million cubic metres per day (equivalent to about 77 litres per person per day).

Iraq relies almost exclusively on reverse osmosis (RO) water treatment systems to desalinate water supplies. Preparation of the guidelines was informed by a survey of existing RO water treatment system sites undertaken by Parsons Brinckerhoff in February and March 2011. A total of 125 government-owned RO plants were surveyed. The survey allowed us to understand issues such as the quality of water sources, the physical state of the plants, the technical capacity of the operations and maintenance staff, as well as the reliability of power sources and potential environmental effects. Approximately half of the plants surveyed were not operational (Figure 2). Of the remaining half, more than three-quarters were only partially operational.

The survey teams identified a variety of issues contributing to the poor operation of these plants, which typically included polluted raw water sources, lack of investment and maintenance (Figure 3), and an unreliable electrical power supply.

The vast majority of the existing reverse osmosis water treatment systems in Iraq are of relatively small capacity, designed to treat between 100-600 cubic metres per day (see Figure 4). Adequate pre-treatment is essential to successful RO plant performance and membrane life and is therefore an essential part of a RO plant design. Adequate and robust pre-treatment will also ensure that systems can cope with fluctuations in raw water quality.

Figure 2 – Non-operational existing RO plant in Basrah

Figure 3 – Poorly maintained RO plant in Kirkuk

Rebuilding Iraq's water management systems

Parsons Brinckerhoff was commissioned by UNICEF in 2011 to undertake a survey of existing reverse osmosis water treatment plants and develop a set of guidelines based on the findings of the survey. Our work formed part of a US$10-million UNICEF program, supported by the European Union, to help develop Iraq's water and sanitation sector. The project was completed in collaboration with the firm's water specialists located in the Middle East, UK, and US offices. A close working relationship was also established with the relevant ministries within the government of Iraq to ensure the long-term success of the guidelines.

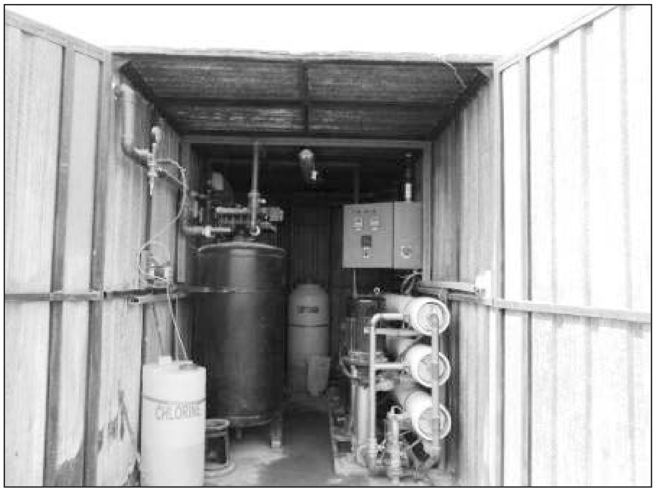


Figure 4 – Small RO plant in Kirkuk

Recommendations were made for the planning, implementation, and operation of RO water treatment systems in Iraq. The guidelines provided information on technical aspects, such as consideration of raw water quality, pre-treatment requirements, generation capacity, appropriate RO system design instrumentation, and post-treatment considerations. Operation and maintenance procedures were considered, with recommendations provided for start-up activities, operational monitoring, manual and online data collection, routine maintenance activities, and common troubleshooting guidelines. The guidelines included estimated costs for the refurbishment and/or construction of new RO water treatment plants and also provided costs of alternative systems to enable comparison with other potentially suitable water treatment methodologies.

Providing technical information is not enough to secure the long-term success of RO systems in Iraq. Equal consideration must be given to how the systems will be planned and operated prior to the procurement or installation of any RO systems, and so information was included for "softer" aspects such as stakeholder engagement, knowledge transfer, planning, and procurement.

Why use reverse osmosis?

Iraq relies almost exclusively on RO water treatment systems to desalinate water supplies. This well established technology is typically used to demineralize seawater and brackish waters or soften groundwater rich in calcium and magnesium. Parsons Brinckerhoff considered RO to be the most cost-effective and suitable technology for the desalination of potable water in Iraq. It is an adaptable technology that can perform under a range of salinity and temperature conditions. RO technology is applicable to a wide range of plant sizes. The continued use of RO in Iraq will therefore allow the systems to be adaptable to different levels of consumer demand in urban, peri-urban, and rural areas. These units are modular, so it is relatively easy to expand the plant size if and when demand increases. This flexibility is particularly important as the Iraqi population is still in a state of flux. Statistics indicated that the majority of refugees and internally displaced people are returning to Baghdad and Diyala, along with an overall and growing shift in population from rural to urban areas.

The drinking water guidelines prepared by Parsons Brinckerhoff will be applied to more than 300 RO plants that exist across Iraq and contribute to the attainment of the United Nations' Millennium Development Goal 7: Ensure environmental sustainability by 2015, thereby improving the overall health and development of Iraq's children.

***Joanna Goodwin** is a Senior Engineer on Parsons Brinckerhoff's water team in the UK and served as Project Manager for the Reverse Osmosis Guidelines project in Iraq.*

In-Situ Pipe Lining – Innovation and Market Acceptance

by **Mike Brockhurst**, Balfour Beatty Water and Gas, Sheffield, UK, +44 (0)779192581, mike.brockhurst@bbusl.com; and **Kathryn Vowles**, Balfour Beatty Water and Gas, Bristol, UK, +44 (0)7876791151, Kathryn.vowles@balfourbeatty.com

Introduction

The challenge of managing and maintaining underground infrastructure, and in particular water pipes, continues to grow as infrastructure ages and new pipes and cables are added, creating an ever more complex underground environment. This paper views innovation through a discussion of combining existing technologies in a way that will facilitate market acceptance and drive a 'step change' in asset management—a development which has many similarities to the growth of 3D printing.

Innovation opportunity

Over recent years there has been increasing coverage about the opportunities created by 3D printing, or 'additive manufacturing'—the creation of a three-dimensional object, normally based on a digital model. The reduction in cost of 3D printers and laser scanning, and the availability of the enhanced computing power needed to develop and share detailed 3D models, has opened up the market and therefore the opportunity.

In actual fact, 3D printing has been around for some time. It is based on 1970s technology which established the inkjet printer (1976). By 1984 the technology had developed enough to produce the first 3D printers. The materials used have changed over time. Printing started with plastics, but metal and glass can now also be used, amongst other materials. Developments of 3D printing in the medical field have perhaps been the most exciting, with the ability to print organs since 2002 and individual blood vessels by 2009. There is still a way to go before these can be replicated in the human body, but the technology is developing apace.

What has this to do with water? In the UK, the water market is changing. Regulatory control is tightening and there is pressure on companies to address water affordability for the end customer. The market structure is moving to a more competitive model and companies are looking to drive significant efficiencies in the management of their assets. The water services regulation authority is requiring a TOTEX (total expenditure) approach that balances capital and operational costs most efficiently. Water companies therefore want greater understanding of asset management liabilities over time. These challenges are replicated elsewhere in the world, where existing underground assets need to be managed effectively in resource-constrained conditions. We are all looking to do more with less.

Technology evolution

In the UK, water companies have been using spray technologies to line underground pipes since before the invention of the inkjet printer. The aim of the spray lining was to avoid replacing sections of pipe and the inherent cost and service disruption associated with that. The lining could be used to improve water quality or, in some cases, improve the structural integrity of the existing pipe.

At that time, a bitumen or cement coating was used. Pipes were cleaned of all residue by opening a valve at one end and cutting the pipe at another. The cleaning was carried out using mechanical borers with rotating heads which dislodged built up scale as they travelled up the water main, while water running through the pipe flushed the scale out into the open excavation. After this cleaning process a spray rod was used to apply the lining. During the 1980s and 1990s until around the turn of the century, an epoxy lining was the norm, replacing the bitumen lining. Cement lining was still carried out for some applications and new pipes may have a factory spun cement lining.

The big disadvantage with epoxy linings was the 16 to 24 hour curing time required. This meant that homes could be without water supply for up to 36 hours to allow for the cleaning, lining, curing, and commissioning of each section of pipe. The next development to address that challenge was the use of polyurea (PU) linings.

E. Wood Ltd. of Northallerton was a company specialising in such linings. It has since been acquired by 3M, who continue to develop the technology and have a close working relationship with Balfour Beatty Gas and Water.

Market Acceptance

E. Wood Ltd developed rapid setting, non-structural lining technology (the 169 range of products) prior to acquisition by 3M. Currently, a new structural enhancement lining material and associated application technology is being developed which can provide significant benefits in relation to long-term asset management. The big challenge is establishing market acceptance. Historically, there were a number of issues associated with spray lining:

- Epoxy, bitumen, and cement were all prone to slumps and failures.
- The best environment for lining was entirely dry, meaning pipes needed to be purged and allowed to dry. This took time and water could still often seep into the pipes creating weaknesses in the lining, and standing water was hard to avoid.

There was therefore a perception in the market that, whilst substantially more expensive and disruptive, slip lining the pipes may be preferable to spray lining.

Technological solutions

Balfour Beatty Water and Gas is working with 3M and technology partners to rethink the use of spray lining, and learn from the experience of 3D printing. There are a number of reasons why 3D printing is gaining market acceptance and considerable growth:

- Reduction in technology costs;
- Development and cost reduction regarding digital modelling and laser scanning, as well as generally more use and knowledge of digital tools across a range of sectors;
- Market drivers in place; and
- Benefits realised for prototyping, specialist technical needs whether engineering or medical, and artisan uses.

There is a strong belief that the current market drivers create the right environment to take a fresh look at spray lining technology. 3M is working to develop a new and more robust structural lining material, Scotchkote Pipe Renewal Liner 2400 (2400), which is applied by 3M authorised applicators using 3M approved rig design. Balfour Beatty is working with 3M to trial new lining techniques and materials. Initial testing of 2400 over a 1.6km distance reduced an estimated 15 working day programme down to 8. This delivered a considerable benefit in terms of both cost and disruption to the local community. The benefits of the new material are summarised below:

- Approved for use in drinking water pipelines in 22 countries;
- Ability to apply on asbestos cement, ductile iron, cast iron, steel, and cement mortal linings;
- Two forms of application from one material, both non-structural and structural enhancement;
- Application suitable on mains 3” to 24” diameter;

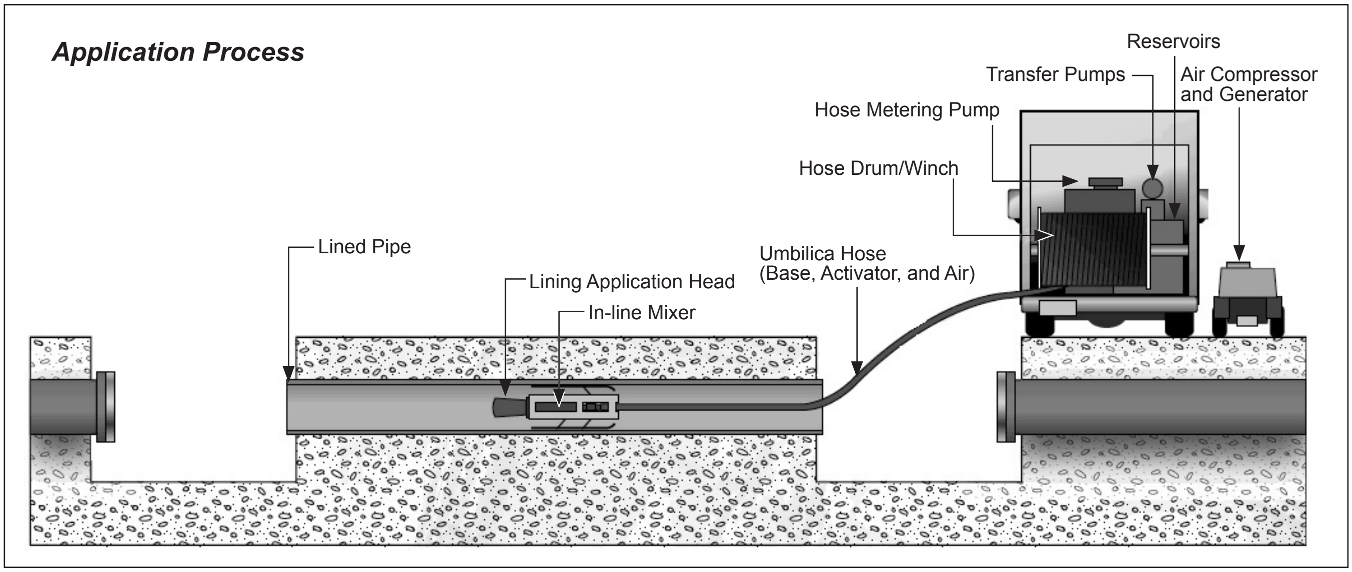


Figure 1 – Application Process (source: 3M)

- Ability to vary lining thickness (up to a uniform 8.5mm thickness in single pass on certain substrates);
- Ability to line up to 200 metres at a time;
- Variable design life of up to 50 years based on customer requirements; and
- Quicker than traditional replacement methods, plus reduced risks.

It therefore fits well with the total expenditure focus for the water companies, and will have significant whole life cost benefits.

Having addressed the reliability and adaptability of the lining material, we also needed to look at further ways of driving market acceptance. To achieve this we are also utilising the digital tools from our Network Intelligence Solutions to support the application of spray lining (see Figure 1 for application process). Taking a new management approach, we will video and laser scan the pipes before applying the spray lining, and again afterwards. This will provide the water company with the comfort of knowing that the lining application has been successful. We will also give the water company detailed information on the pipe to allow it to make future asset management decisions. The reduction in technology costs, and the development of 3D modelling software and laser scanning, facilitates this extra step which results in a number of benefits for the client, in line with their current market drivers. The important next stage is to understand and communicate the range of benefits realised from this approach, and use that evidence to develop the market further.

Next Stage

Balfour Beatty is working with technology partners and John Moores University in Liverpool, England to develop robotic technology that would allow us to place a ferrule into the pipe junctions whilst spray lining is taking place, which would protect the points where the pipes link to homes and businesses, therefore allowing the approach to be applied in more locations. The Balfour Beatty team is also on the advisory board for the University of Leeds Centre for Mechatronics and Robotics and its EPSRC (Engineering and Physical Sciences Research Council) National Facility for Innovative Robotic Systems. The university is engaging with industries, including construction, to advance the potential applications of autonomous systems. As robotic tools develop, there will be a time when autonomous camera technology can be used to identify leaks or damage to underground pipe networks, and then robotic repair devices can effectively ‘3D print’ repairs, affording a further integration of existing technologies to solve infrastructure challenges and drive even greater efficiency.

Conclusion

In conclusion, innovation often comes from a combination of existing materials, technologies, and management processes brought together to address a well-defined business need. Only time will tell if spray lining will gain international market acceptance and be a key tool in the management of underground water assets, and if through the use of robotics we can focus on even more surgical repair. With in-built robotic support systems, our underground infrastructure may even become self-managing and self-repairing.

Mike Brockhurst *is Innovation Strategy Manager for Balfour Beatty Water and Gas. He has over 30 years' experience in the water sector and has worked extensively in the development and application of pipeline rehabilitation technologies.*

Kathryn Vowles *worked for Parsons Brinckerhoff for 11 years, latterly in the strategic consulting group. She is now working on business development, strategy, and intelligent infrastructure projects for the Balfour Beatty Services Division.*

Upgrading the Preliminary Treatment Works (PTWs) in Hong Kong's Victoria Harbour Area

by **Louis Chan**, Hong Kong, +852 2579 8650, chan.louis@pbworld.com

In previous decades, municipal sewage in the urban areas of Hong Kong was collected and treated at preliminary treatment works (PTWs) along the coastal areas of Hong Kong Island and Kowloon and then discharged directly into Victoria Harbour. In anticipation of population growth and to improve water quality in the harbour, the Harbour Area Treatment Scheme (HATS) project was launched by the government of Hong Kong. The goal of this mega-scale sewage collection and treatment system project is to collect effluent from the PTWs on both sides of Victoria Harbour (i.e., Hong Kong Island and Kowloon) and convey it to a centralised plant for further treatment prior to disposal via a long submarine outfall.

The HATS scheme was designed to be implemented in stages. Stage 1 was fully commissioned in 2001 and consisted of the following: the upgrade of seven preliminary treatment works (PTWs), construction of Stonecutters Island Sewage Treatment Works (SCISTW), and construction of a 23.6km-long deep underground sewage conveying tunnel. The objective of Stage 1 was to treat 75 percent of sewage generated from a population of 4.5 million people living in the Victoria Harbour sewage catchment area. Stage 2 is meant to address the collecting, treating, and conveying of the remaining 25 percent of the sewage from the respective catchment to the SCISTW, and is further divided into phase A and phase B.

The HATS project is now in Stage 2A, with Parsons Brinckerhoff commissioned by the contractor, Jardine Engineering Ltd., to undertake detailed design for the upgrade of eight PTWs. Stage 2A also involves the construction of an approximately 21km-long deep tunnel system to convey the sewage from Hong Kong Island to SCISTW, where the existing chemical treatment facilities will be expanded. The eight PTWs in Stage 2A are located on the north and southwest shore of Hong Kong Island at the following locations: North Point, Wan Chai East, Central, Sandy Bay, Cyberport, Wah Fu, Aberdeen, and Ap Lei Chau. These are dense urban areas and therefore the work is subject to various constraints, particularly to the availability of construction work space. This article addresses the design challenges of the upgrade work which included: the formulation of upgrading sequences, plant hydraulics, maintaining treatment plant operation, and optimisation of the odour control system. Figure 1 illustrates the schematic layout of Stage 1 and Stage 2A.

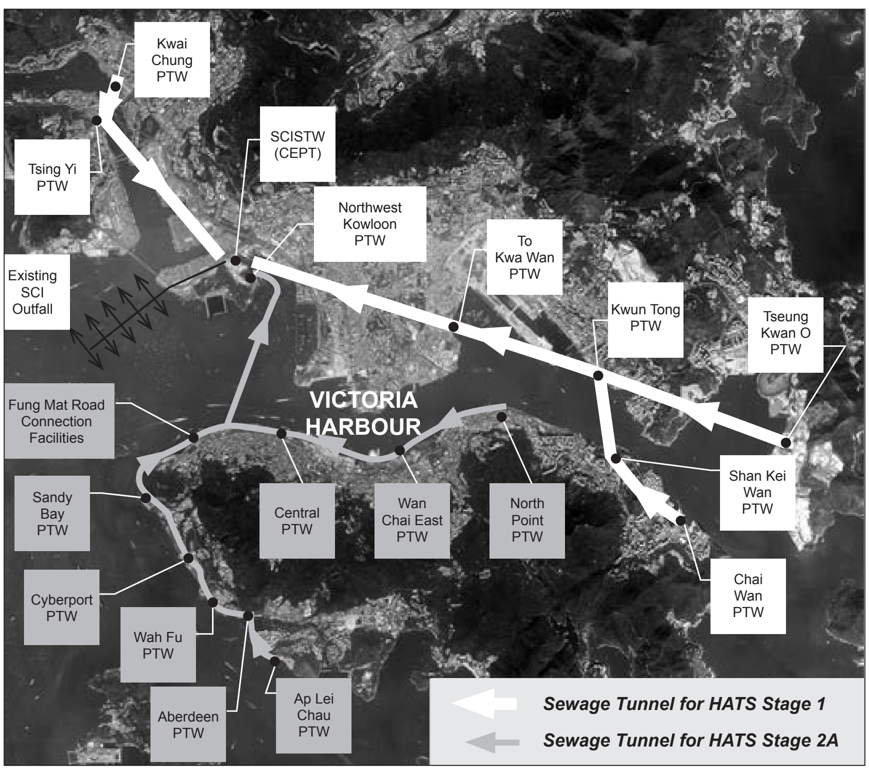


Figure 1 – Schematic Layout of Stage 1 and Stage 2A System

Existing PTW Upgrade Requirements

The contract, issued by the Drainage Services Department of the Hong Kong Special Administrative Region (HKSAR), specified the upgrade requirements for each PTW which included the following:

PTWs will meet the treatment objectives of the project

The objective of the project is not to increase the treatment level of all the PTWs from the current preliminary level but to pre-treat the raw sewage prior to discharge to the sewage conveyance system (SCS), to remove large solids and grits in order to avoid accumulation inside the tunnel system, and to protect downstream facilities from damage or blockage.

Capacity of the existing PTW will provide for future flow demand

In assessing the PTW upgrade requirements, an important criterion is whether the capacity of the existing PTWs is capable of handling sewage flow in the ultimate scenario (i.e., the maximum sewage flow from the catchment area). Table 1 shows the capacity of the PTWs and the respective ultimate sewage flow.

PTW	Existing Capacity (m^3/s)	Sewage Flow in ultimate Scenario (m^3/s)	Upgrading of Capacity Required
North Point	3.43	3.98	Yes
Wan Chai East	4.61	5.67	Yes
Central	3.72	4.74	Yes
Sandy Bay	0.31	0.44	Yes
Cyberport	0.35	0.27	No
Wah Fu	1.09	0.31	No
Aberdeen	2.08	3.06	Yes
Ap Lei Chau	1.20	1.36	Yes

Table 1 – Capacities of PTWs and sewage flow in the ultimate scenario

Configuration of the PTWs will conform to the HATS Stage 2A system

Presently, the effluent from the PTWs is discharged into Victoria Harbour via an outfall which may cause water quality deterioration in Victoria Harbour. After completion of Stage 2A, all the effluent will be discharged to a sewage conveying system (SCS) via drop shafts within the PTWs to be transported to a centralized sewage treatment works in Stonecutters Island for further treatment. Due to the deep underground tunnel characteristics of the SCS system, the PTW discharge configuration must be modified accordingly.

Condition and serviceability of the existing equipment are to be determined

The condition and serviceability of the existing equipment are to be evaluated in the upgrade. In the case of the Wah Fu PTW, although the equipment met the capacity requirement for flow demand, the equipment had reached the end of its service life and demolition was required.

The upgrade will enhance the PTW operation

As part of the upgrade, the following systems will be enhanced:

- All activated carbon-type deodorisation systems will be replaced by biotrickling filters, which are less costly than the activated carbon replacement options; and
- The existing supervisory control and data acquisition (SCADA) system will be replaced by a distributed control system (DCS) which will be integrated with the overall HATS control system.

<table>
<tr><th>PTW</th><th>Inlet Pumping Station</th><th>Sewage Screening and Treatment</th><th>Odour Control</th><th>Control System</th></tr>
<tr><td>North Point</td><td>Upgrade not required</td><td>Replacement of existing treatment facility with a new treatment building</td><td rowspan="8">Replacement of existing system with new foul air extraction ducts and deodorisation system</td><td rowspan="8">Replacement of the existing control system with a DCS system that will be integrated with the HATS control system</td></tr>
<tr><td>Wan Chai East</td><td rowspan="2">Replacement of existing pumps and pipework with new pumps and pipework</td><td>Upgrade of most treatment equipment not required</td></tr>
<tr><td>Central</td><td>Replacement of existing treatment facility with a new treatment building</td></tr>
<tr><td>Sandy Bay</td><td>Upgrade not required</td><td rowspan="2">Replacement of existing approx. 6mm fine screens with new fine screens with 4mm bar spacing</td></tr>
<tr><td>Cyberport</td><td>Upgrade not required</td></tr>
<tr><td>Wah Fu</td><td>Not Applicable</td><td>New treatment building</td></tr>
<tr><td>Aberdeen</td><td>Replacement of existing pumps and pipework with new pumps and pipework</td><td>New treatment building</td></tr>
<tr><td>Ap Lei Chau</td><td>Not Applicable</td><td>New treatment building</td></tr>
</table>

Table 2 – Summary of Upgrade Requirements of PTWs

Summary of Upgrading Requirements for each PTW

Taking into account the upgrade objectives presented above, Table 2 summarises the upgrading requirements of each PTW. An upgrading strategy needed to be formulated based on the requirements for each PTW. It was necessary to ensure that the current PTW remained operational during the upgrade and that various site constraints, including available construction work space for the upgrade, were addressed. For this article, the Aberdeen PTW is used as a representative PTW to illustrate the issues that needed to be considered.

Description of Existing Aberdeen PTW

The treatment process of the Aberdeen PTW prior to Stage 2A is illustrated in Figure 2, which shows the raw sewage undergoing screening and grit removal prior to discharge to the sea.

Challenges of Upgrading

The upgrading of this PTW was complicated by limited construction space and a significantly increased sewage flow (the ultimate flow scenario). The existing PTW treatment equipment needed to be replaced with new equipment to satisfy the following conditions:

- Treated sewage will be discharged into the sewage conveyance system via a drop shaft (a vertical tunnel that conveys the effluent from the ground level PTW to the deep tunnel SCS) instead of being discharged by marine disposal; and
- Based on the operation experience in HATS Stage 1, a medium screening process is not required.

Because of the various site constraints, the upgrading sequences needed to be carefully planned. Parsons Brinckerhoff, as the contractor's designer, formulated the upgrading sequences. They were divided into two parts: one for the inlet pumping station and the other for the PTW treatment equipment downstream of the inlet pumping station.

Upgrading Sequences

Inlet Pumping Station

The upgrade of the inlet pumping station was subject to the following constraints:

- Normal operation of the pumping station had to be maintained;
- Only one pump at a time was allowed to be taken out of service during the upgrading;
- At least one rising main had to be maintained at any time; and
- The pumping station building structure had to be retained.

Based on the above constraints, the associated upgrade work was divided into the four phases (see Figure 3). Each phase requires an outage of one pump at a time for the work.

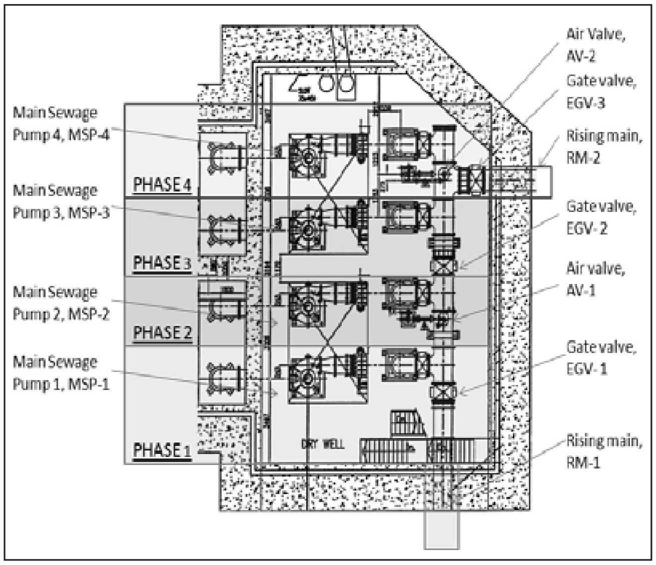


Figure 3 – Phases of Upgrading Work for Inlet Pumping Station

As the capacity of the pumping station varies during the upgrade process, it was necessary to tabulate the anticipated pumping station capacities for all stages.

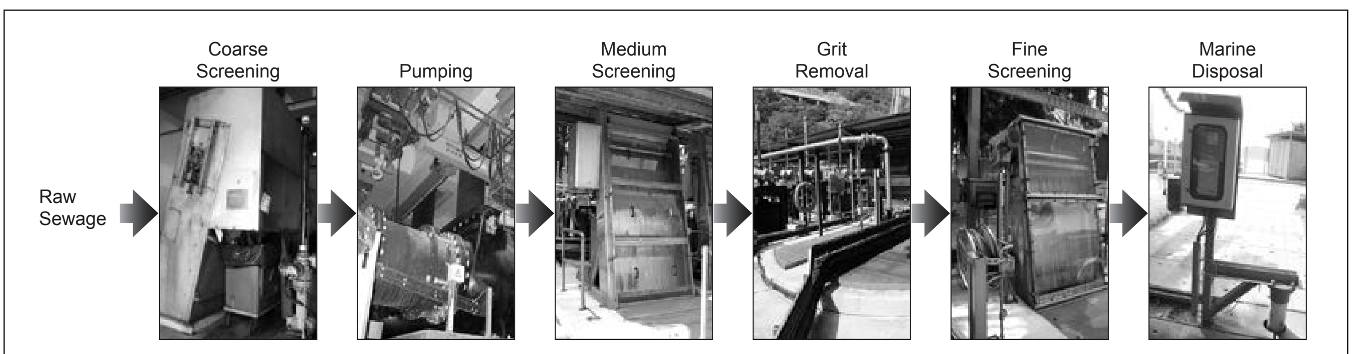


Figure 2 – Treatment Process of Existing Aberdeen PTW

Preliminary Treatment Work Downstream of the Inlet Pumping Station

Various site constraints were encountered in the upgrade of the Aberdeen PTW, downstream of the inlet pumping station, necessitating the work to be done in situ (see Figure 4).

The sequence of work formulated by Parsons Brinckerhoff for the upgrade of this congested site was carefully coordinated in order to maintain operation of the Aberdeen PTW. The construction sequence was designed to take place in eleven successive steps so operation of the PTW could be maintained throughout.

In carrying out the upgrade work, it was inevitable that sections of access road be closed. Nevertheless, with appropriate site traffic adjustment, partial road closures did not impact site accessibility.

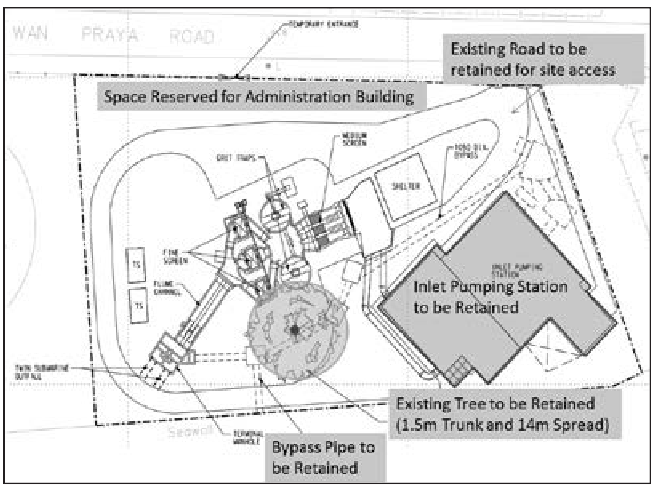


Figure 4 – Various Site Constraints in Aberdeen PTW

Odour Control in the Aberdeen PTW

The PTWs are situated in urban areas and thus odour control was important in the formulation of upgrading requirements. The following design optimized the odour control system:

Use of environmentally friendly biotrickling filters

In the existing PTW, odour is controlled by activated carbon embedded inside the filter media, which absorbs H_2S and organic gases in the exhaust air prior to discharge to atmosphere. The major disadvantages of this type of filter are the costly replacement and the careful handling required of the exhausted activated carbon to avoid generating secondary pollution.

Biotrickling filters were proposed to replace all activated carbon filters. However, under the same air flow condition, the size of a biotrickling filter is usually much larger than an activated carbon filter, requiring higher retention time for the slower biological oxidation processes for treating the odorous gases. Therefore, to fit into this congested site, the biotrickling filters required other ventilation system modification measures.

Optimisation of Odour Control Measures

The following modifications are being implemented to minimise the flow rate of foul air and optimise the performance of the biotrickling filter systems:

- Positive pressurisation of the non-odour source areas by a normal mechanical ventilation system. This is achieved by manipulating the flow rates of the fresh air supply and exhaust air extraction.
- Covering all the odour sources, such as sewage flow channels and screening skips, to prevent the release of odorous gas to other areas.
- Negative pressurisation of the odour source areas by a mechanical foul air extraction system leading to the deodorisation system. This is achieved by manipulating the flow rates of fresh air supply and/ or exhaust air extraction. The biofilter-type deodorisation system uses bacteria inside the filter to oxidize the odour causing gases.

With the proper implementation of the above measures, the foul air flow rate can be significantly reduced to at least 50% of the current flow rate.

Conclusion

This project presented various challenges such as a congested site area and the maintenance of plant operation during construction. Through the efforts of the project team, obstacles were overcome and construction is currently in progress in accordance with the work sequences formulated by Parsons Brinckerhoff. Construction is expected to be completed in 2015.

Louis Chan *is a Mechanical Engineer with over 20 years' experience in the design of waste and sewage treatment facilities, ventilation systems for tunnels, and other electrical and mechanical facilities for infrastructure projects. His expertise also includes chemical engineering, computational fluid dynamics, and computer engineering. He was treatment process design leader on the Ngong Ping Sewage Treatment Works, and on the commissioning of Tai Po STW Stage 5 Phase 1, and HATS Stage 2A.*

Wastewater Reduction in Road Tunnel Air Purification Systems

by **Catherine Mok**, Hong Kong, 852-2579-7071, mok.catherine@pbworld.com; **William Xie**, Beijing, China, 8610-65848645, xie.william@pbworld.com; and **Steven Lai**, Hong Kong, 852-2963-7625, lai.steven@pbworld.com

Air Purification Systems (APS) have been applied to many road tunnel projects around the world in order to maintain tunnel air quality and/or reduce tunnel emissions. Various types of APS used in road tunnel applications have proven records of success in Europe, Japan, and other countries (e.g., Laerdal Tunnel in Norway, Túnel Sur M30 in Spain, M5 East Tunnel in Australia, Aioi-cho Tunnel and Central Circular Route Shinjuka Line Tunnel in Japan). However, less than ten projects use APS to remove both dust and nitrogen dioxide (NO_2) or mono-nitrogen oxides (NO_x).

A new road tunnel is being constructed in an urban district of Hong Kong. Eight APS plants will be installed in three ventilation buildings of the tunnel. To satisfy the environmental requirements, an electrostatic precipitator (ESP) to remove dust has been installed. To further improve the environment, equipment for removing NO_2 is also provided in the project. The efficiency of an APS for removing the dust particulates and NO_2 from the airflow stream is over 80%. The proposed APS is one of the largest in the world. Parsons Brinckerhoff is the designer for all the electrical and mechanical (E&M) systems of the project, including the APS. Since a significant amount of wastewater will be generated from the APS, one of the main challenges of the design is "to avoid converting air pollution to water pollution".

Air extracted from the tunnel will first pass through the electrostatic precipitator (ESP) and the de-nitrification modules of the APS, and then continue its path across the tunnel.

Electrostatic Precipitator (ESP)

An ESP is an electrical device that captures dust particles within the airstream by using electrostatic principles. The ESP has a two-stage structure comprised of ionizing and collecting sections. In the ionizing section, a high positive voltage is applied to discharge poles, and suspended particulates from the tunnel exhaust are electrostatically charged when passing through this area. In the collecting section, a strong electric field is formed between a high voltage plate and the collection plates when a high positive voltage is applied between them. As a result, charged particulates are attracted to the collection plates.

De-nitrification (De-NO_2) Filter

De-nitrification is a complicated chemical process. After the exhaust air is treated by the ESP, the air will pass through the de-nitrification device where NO_2 in the air will be absorbed. The material absorbing NO_2 is made of activated carbon.

Wastewater is mainly generated from the ESP cleansing system. Reducing the amount of wastewater from the ESP is one of the key considerations in the design. The collection plates of ESP require frequent cleaning with water to maintain the performance. A significant amount of wastewater is discharged from this washing process. In order to reduce the amount of wastewater, Parsons Brinckerhoff specified the following requirements for the sub-systems:

- Automatic control system - Particulate monitor sensors will be installed in the inlet and outlet of the APS to record the concentration of respirable suspended particulates (RSPs). The plates will only be washed when the reduced efficiency fails to meet the requirements.
- ESP washing distribution system - Pressurized water is used to increase the efficiency of soot and dust particle removal. Spray nozzles will be fitted on the front and the back of the ESP filter modules. By using this washing distribution system, the washing time is shortened and water consumption is reduced.
- Filtration system - The wastewater from the ESP is discharged through a filter where the dust particles are transferred to the pneumatic system, while the filtered water is released to the water recycling system.

- Water recycling system - The filtered water is collected in a tank below the filter and pumped back to a water treatment tank for recycling. The particle-free water will be used for the next washing and, therefore, the water top-up[1] is reduced to compensate the losses.

Figure 1 shows an example of ESP cleaning system installation (washing, filtration, and recycling).

Figure 1 – An ESP Cleaning System Installation *(Source: Aigner)*

The associated APS equipment room, which supports the daily operation of the whole APS system, occupies less than 3% of the floor area of the ventilation building. After each wash down, more than 95% of the water will be recycled and, after certain cycles, the water will be

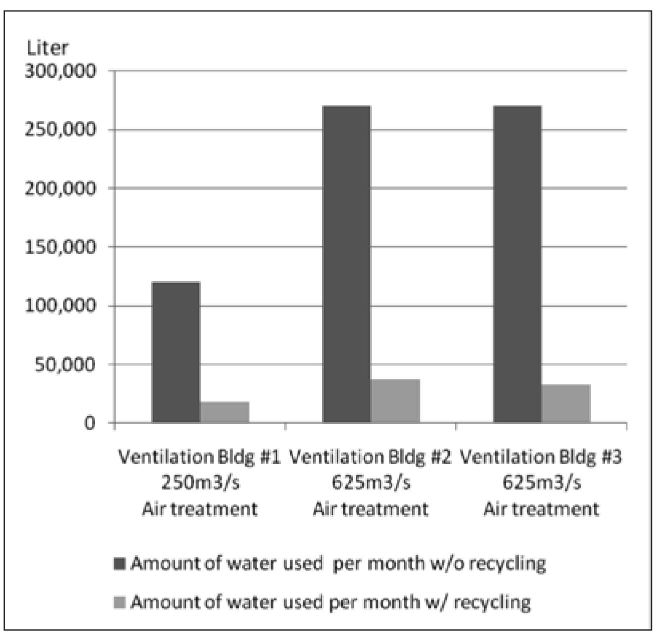


Figure 2 – Water usage for cleaning and the amount of water recycled for each ventilation building

totally replaced and discharged, resulting in an overall recycling rate of 90%. The discharged wastewater shall meet local environmental requirements. The discharged wastewater does not contain detectable substances of environmental concern such as cyanogen, lead, cadmium, all mercury, hexavalent chromium, arsenic, organic phosphorus, alkyl mercury, and polychlorinated biphenyl. As a huge amount of wastewater is recycled, only a small amount of water top-up is required. It is estimated that the annual savings of water usage for all ventilation buildings in the tunnel will be more than 7,000m^3. Figure 2 shows the water usage for cleaning and the amount of water recycled for each ventilation building.

Parsons Brinckerhoff makes significant contributions in a number of ways to reduce the amount of wastewater discharged from APS. The ESP system and associated cleaning system is not a new technology; however, there are limited market players. Different suppliers have different configurations for their APS and, hence, different spatial and E&M requirements. It is essential that the major parameters of the ESP cleaning systems are specified in the tender document and that a sufficient number of market players can join the competition. Parsons Brinckerhoff has considered all features and spatial constraints and developed a design that is feasible for at least 5 suppliers to bid for the project, thereby providing fair market opportunities while reducing water usage and meeting local environmental requirements.

Catherine Mok *is a Mechanical Engineer who participates in road tunnel and metro projects and has experience in building information modeling (BIM), Subway Environment Simulation (SES), and Primavera P6 on projects.*

William Xie *is a Mechanical Engineer with over 10 years of experience in road tunnel and metro station design. He was the tunnel ventilation engineer for a road tunnel project which will use an Air Purification System (APS) for the first time in Hong Kong*

Steven Lai *is a Mechanical Engineer and Senior Professional Associate at Parsons Brinckerhoff. With 24 years of experience, he has served as lead engineer on many tunnel ventilation system and environmental control system related projects. He is MEP Project Manager for a road tunnel project in Hong Kong which will use an Air Purification System (APS) for the first time in Hong Kong.*

[1]Top-up - an amount needed to restore something to its former level

Developing a Clean-up Strategy for Queensland's Worst Mine Spill

by **Gary Thorne**, Perth, AUS, +61 8 92163680, thorneg@pbworld.com; and **Vanessa Personnaz**, Brisbane, AUS

Across Australia, mine wastewater management has been based on solar heat and wind to naturally evaporate wastewater. With more extreme weather conditions becoming commonplace, storm ponds and tailings dams can easily reach maximum capacity and, in some cases, spill over into the environment.

After a heavy rainfall event in early 2009, several North Queensland mine sites experienced flooding. At least two sites had unintentional mine water releases to the environment and a third was 3,381 mega litres (892 million gallons) over its agreed maximum level, at which point the local environmental agency was notified and an action plan submitted.

Heavy rainfall events are not uncommon in Southeast Asia, where treating the mine wastewater by natural evaporation is not possible, and treating the mine wastewater for continuous discharge to the environment and reuse are becoming standard practice there, and maybe something Queensland mining could consider in the future.

Parsons Brinckerhoff was employed by the receiver of one mine and the owners of two other copper mines to review water issues, develop strategies, and provide construction management of repair and remediation work. This article describes Parsons Brinckerhoff's involvement at a copper mine site that was in receivership and was unproductive at the time of a heavy rainfall and, due to a number of incidents, led to an unintentional discharge of mine wastewater to a nearby creek.

Flooding at the Lady Annie Mine

In January and February 2009, 1191mm of rain were recorded to have fallen at the Lady Annie mine area. Rainfall records indicated that these levels of rain had only previously occurred in the years 1893 and 1974.

The Lady Annie mine area stormwater pond system was designed in such a way that, if it reached capacity, the ponds would inundate the leachate pond system prior to discharging via the stormwater spillways to Saga Creek. The total stormwater pond capacity was 770 mega litres (203 million gallons) and the ponds contained minimal amounts of water before the rainfall event.

Within a three-day period, the mine site received more than 340mm of rain, resulting in uncontrolled releases. Water seeping under two leach pad liners triggered ponding on the surface, causing the stormwater to combine with leachate. This meant the stormwater entering the ponds was highly contaminated.

The intensity of the rainwater surface flow and extensive erosion around the stormwater ponds led to a sinkhole appearing close to the pond wall (see Figure 1). A section of the pond wall eventually collapsed causing damage to the pond liner. An estimated 447 mega litres (118 million gallons) of contaminated stormwater was discharged into Saga Creek. The discharge triggered immediate action to mitigate the impacted watercourses extending about 54km downstream.

Figure 1 – Stormwater pond wall collapsed due to sink hole

Impacted Area Levels		*ANZECC 2000 Guideline Values*	
Contaminant	***Contaminant recorded levels (mg/L)***	***Livestock allowable Drinking Water Values (mg/L)***	***95% Trigger Value (mg/L) for a moderately disturbed ecosystem***
Aluminium	***0.5 to 90***	***5***	*****
Cobalt	***0.17 to 4.6***	***1***	***-***
Copper	***1.9 to 56***	***1***	***0.0014***
Nickel	***0.08 to 1.6***	***1***	***0.011***
Conductivity	***170 to 2600***	***5970***	***250***
Sulfate	***64 to 1700***	***1000***	***-***
Chromium	***<0.001 to 0.03***	***1***	***0.0001***
Manganese	***1.2 to 30***	***-***	***1.9***
* 0.055 if pH >6.5; 0.0008 if pH <6.5			

Table 1 – Lady Annie Water Quality Results – February 2009

Table 1 shows the sampling results from the impacted creeks directly after the discharge and the corresponding guideline contaminant levels, which trigger notification to the local environmental bureau office. The highest levels of contamination were found in the first 11km from the point of discharge.

Throughout the impacted 54km of creeks, the pH was recorded at approximately 4.5, whereas unimpacted areas were at pH 6.5 to 7.0. In May 2010, sampling showed that copper remained above the ANZECC 2000 95% trigger level in a number of areas.

Location-specific difficulties complicated the ability to treat the contaminated water. Areas of cultural significance to indigenous people combined with rugged terrain and limited access made transporting a more traditional treatment method, such as a bank-side water treatment plant, unfeasible. Community unrest prompted extensive negotiations with local land owners and stakeholders to obtain approval of treatment strategies.

Due to the Lady Annie unintentional mine wastewater discharge in 2009, cattle were restricted from using the contaminated creek area for drinking purposes and cattle farmers had to relocate thousands of cattle to alternative locations with suitable water quality. After successful remediation of the creek, the aquatic ecosystem had recovered to a level which allowed restriction on cattle drinking from the creek to be lifted at the end of 2011 (see Figure 2).

Remediation Strategy

As part of the creek remediation strategy, Parsons Brinckerhoff facilitated several workshops which included the Queensland Environment Protection Authority and the Department of Mines and Resources (later combined to form the Department of Environment, Resources Management). Through the workshops, Parsons Brinckerhoff developed an innovative remediation procedure, which allowed the use of collected (200 mega litres) non-contaminated rainwater to flush the contaminants to an accessible area where gated culverts were installed. During the remediation the

Figure 2 – Cattle returning to Saga Creek (2012)

gates were closed, which allowed in-stream treatment using bauxsol to reduce bioavailable metals and neutralise acidity. Once the bauxsol had settled and the contained water was proven to be uncontaminated, the culvert gate was opened to allow flushing to the next gated section.

The culverts would remain as a permanent feature to allow the gates to be closed in the event of remobilisation of any undersurface contamination or any future unintentional releases.

Bauxsol, also known as “Red Mud“, is a high pH bauxite slurry which has a proven track record for settling metals in a contained area. There were initial concerns that the sediment in the waterways would limit the ability to quickly return the ecosystem to its pre-discharge state. Acid testing on bauxsol sludge indicated re-absorption was minimal, below pH 3.8. Under the instruction of the Department of Environment, Resources Management (DERM), settled bauxsol sludge was removed from the treated creek areas.

Parsons Brinckerhoff also reviewed the mine site issues which led to the unintentional discharge and, under its construction management role, developed and monitored a repair strategy for the leach pads and stormwater ponds. The cost of repairing the pond subsurface conditions, liners, walls, surface drainage, and the remediation of the creeks exceeded AUD$11m.

Conclusion

In 2012, DERM was successful in its court action against the mine owners at the time of the incident. The court handed down a $500,000 fine (the largest fine issued for such an incident at this time) and ordered the company to pay $83,109 in investigation costs. Department of Environment, Resources Management stated on its website that the Lady Annie mine area incident was the worst mine water spill recorded in Queensland history.

A nearby mine was also issued a $130,000 fine after a portion of the tailings dam had eroded away, causing a much smaller unintentional release of contaminated water to a contained area affecting 11km of creek.

Parsons Brinckerhoff continues to manage the annual water quality monitoring and reporting on the environmental and ecological condition of the creeks as required by the environmental protection order issued to the owner, receivers, and managers at that time.

Gary Thorne *is a Principal Water and Process Engineer with over 35 years' experience in the consulting and contracting professions in developed and developing countries. His experience includes conceptual and detailed design, construction, commissioning, testing, and operation of a wide range of water, wastewater, and sludge treatment plants.*

Vanessa Personnaz, *a former Parsons Brinckerhoff employee, has experience in water quality monitoring, audit, analysis and process design/troubleshooting.*

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Contact editors John Chow (chow@pbworld.com) and Susan Lysaght (lysaght@pbworld.com).

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Executive Editor: John Chow, New York, NY, chow@pbworld.com
Editor: Susan Lysaght, Lancaster, PA, lysaght@pbworld.com
Graphic Designer: Suzanne Daloisio, Lancaster, PA, daloisiosl@pbworld.com
Advisor: Judy Cooper, New York, NY
Guest Reviewers for this issue: Karen Block, Houston, TX; Alan Knott, Manchester, UK; Steven Lai, Hong Kong; Andrew Lawrence, Singapore; Chin Lien, Baltimore, MD; Tom Mosquera, Sydney, AUS; Jonathan Ralph, Bristol, UK

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