

# A Geotechnical Guide for Pump Stations Projects in the Sydney Region

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Summary: This paper provides a guide to geotechnical requirements at the investigation, design and construction stages for typical sewage pump station projects in the Sydney region. This guide is based on experience gained from over 230 pump station upgrades carried out as part of the SewerFix Pump Station Project (SewerFix) between 2001 and 2004.

Large, multi-site projects such as SewerFix provide an excellent opportunity to develop a systematic method of collecting and calculating geotechnical information. It is anticipated that the protocols developed during the project may be applied to other similar programs with a view to improved efficiency.

The paper also presents the benefits of conducting such a project under an alliance contract arrangement, which facilitates continual geotechnical input throughout the lifecycle of each pumping station and the project as a whole.

## INTRODUCTION

The SewerFix program is a \$200 million infrastructure project involving the upgrade of more than 300 pumping stations over a four-year period. The program extended throughout Sydney, the Blue Mountains and the Illawarra region. Each pumping station site represented a project in itself, with varying scope, environmental and economic constraints. Several of the stations programmed for upgrade required capital expenditure exceeding one million dollars.

The aims of the project were essentially to:

- Improve operational reliability of the existing sewage pumping stations;
- Provide for future growth; and
- Comply with the Environmental Protection Authority's (EPA) licensing requirements for sewage transport systems, thus reducing sewage overflows and protecting public health and the environment.

The project was delivered to the client, Sydney Water Corporation (SWC), under an alliance or "friendship" contract. The alliance team comprised Bovis Lend Lease, CH2MHill, the Phillips Group, Sinclair Knight Merz, Sydney Water and Tenix Alliance. Sinclair Knight Merz (SKM) acted as design engineers under the contract with whom the author was engaged for the duration of the project design phase.

This paper describes the investigation, design and reporting methodology adopted throughout the SewerFix project. It will also look at the role of geotechnical involvement in the construction phase of the project and present a case study of a problem site and associated lessons learned.

Geotechnical input was provided on a total of 105 stations throughout the Sydney metropolitan, Blue Mountains and Illawarra regions. These sites covered a wide spectrum of geological environments with sub-surface conditions ranging from low lying alluvial flood plain environments through imported fill sites, shallow Hawkesbury Sandstone sites and steep, rocky sites.

## GEOLOGY

The pumping station sites making up the SewerFix program can be categorised in terms of three geographical regions:

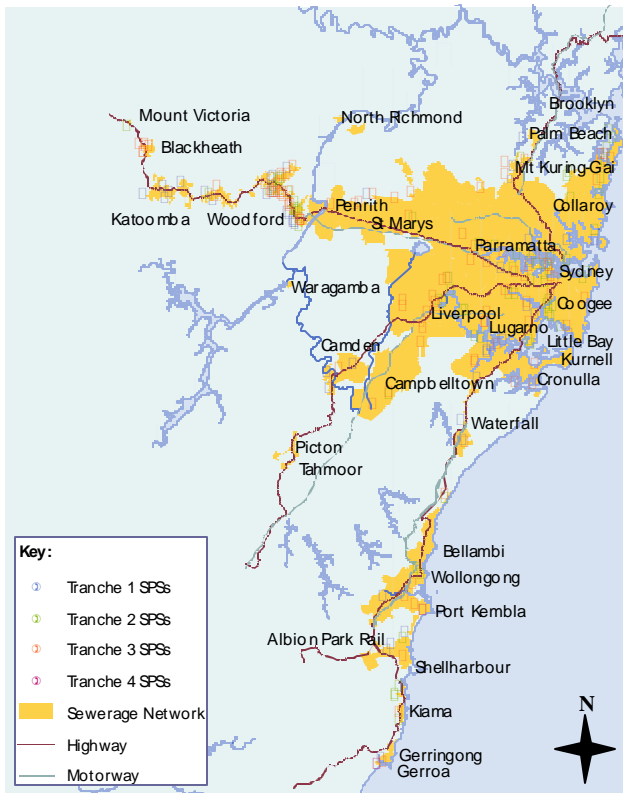
- Sydney Metropolitan;
- Illawarra; and
- Blue Mountains.

The extent of these regions and the site locations are shown below on **Figure 1**.

The geology of these regions has been subject to numerous studies and is generally well understood. Typically, the geology of the Sydney region comprises Triassic Sandstones and Shales with minor occurrences of Quaternary sediments, Branagan, (1).

The Blue Mountains region is generally made up of plateau, cliff and valley landscapes. The plateau and cliff features are typically sandstone above the sandstones, mudstones and coal measures of the Sydney Basin.

The geology of the Illawarra region includes the Hawkesbury Sandstone, Narrabeen Group, Wianamatta Group and the Illawarra Coal Measures. Unique geological units occur as intrusive and extrusive igneous features through sedimentary rocks (eg Gerringong Volcanics).



**Figure 1 SewerFix Project Location Map**

As a large proportion of pumping stations are gravity fed, they are commonly located in natural low points within a catchment; for example at the base or on the side of a valley, on the edge of a creek or drainage path, or on the coast. For this reason, alluvial sediments and imported fill formed major constituents in the geological environments encountered at many of the pumping station sites.

## INVESTIGATION METHODOLOGY

### Geotechnical Investigations

Geotechnical assessments were required at the majority of the stations undergoing civil upgrade works in order to identify geotechnical and environmental constraints and interpret ground conditions for structural design.

The geotechnical requirements for each site were scoped up according to the upgrade works proposed for each station. A site-specific investigation methodology was then developed in order to achieve these requirements and a geotechnical site investigation conducted within the environmental and community framework dictated by the program.

On a site level, typical geotechnical objectives were to:

- Characterise the subsurface geotechnical and groundwater conditions;
- Provide recommendations on possible footing types, founding levels and serviceability bearing pressures for any proposed structures;

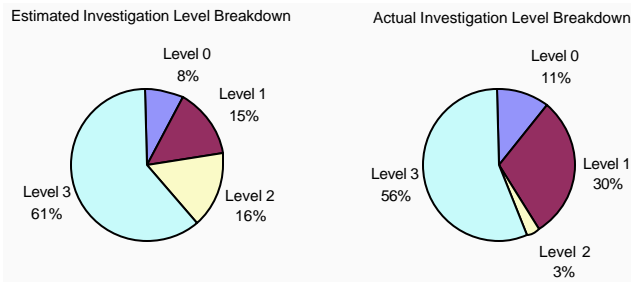
- Assess likely excavation conditions, support requirements and uplift issues; and
- Provide advice on geotechnical and environmental issues such as site contamination and waste classification, acid sulfate soils, slope stability and effects on existing or proposed adjacent structures.

At the proposal stage the investigation requirements for a given pumping station site were broadly grouped into four investigation levels based on the scope of the proposed upgrade works. **Table 1**, below, outlines the investigation level, associated scope of works and typical investigation and testing methodology.

**Table 1 Site Investigation Levels**

| Level | Scope of Works   | Investigation and Testing   |
|-------|--|---|
| 0     | - No works;<br>- Electrical upgrade.   | -No fieldwork or testing;<br>-Desk study if required  |
| 1     | -Underground structures typically $\leq 2.5\text{m}$ deep;<br>-Above ground structures;<br>-Roads/pavements and turning areas. | <i>Site Inspection:</i><br>-Hand augered boreholes;<br>-Dynamic Cone Penetrometer tests (DCPs);<br>-Geological mapping.<br><i>Testing:</i><br>-Disturbed soil sampling (min 1 sample per soil/fill unit or 1 per m depth);<br>-Acid sulfate soil screening, corrosion assessment;<br>-Peroxide Oxidation Combined Acidity and Sulfate (POCAS) testing if required; and<br>-Contamination Testing.   |
| 2     | -Underground structures typically $> 2.5\text{m}$ deep but $\leq 3\text{-}4\text{m}$ deep;<br>-Pipelines.                      | <i>Test Pit Investigation:</i><br>-Test pits excavated with rubber tired backhoe or similar;<br>-Disturbed soil sampling;<br>-DCPs;<br>-Geological Mapping.<br><i>Testing:</i><br>-Disturbed soil sampling (min 1 sample per soil/fill unit or 1 per m depth);<br>-Acid sulfate soil screening, corrosion assessment;<br>-POCAS testing (if required); and<br>-Contamination Testing.   |
| 3     | -Underground structures typically $>3\text{-}4\text{m}$ deep;<br>-Pipelines<br>microtunnels                                    | <i>Borehole Investigation:</i><br>-Cored or non-cored boreholes minimum 1, generally 2);<br>-Disturbed soil sampling;<br>-Undisturbed soil sampling (where appropriate);<br>-Piezometer installation (where appropriate);<br>-Geological mapping.<br><i>Testing:</i><br>-Disturbed soil sampling (min 1 sample per soil/fill unit or 1 per m depth);<br>-Acid sulfate soil screening, corrosion assessment;<br>-POCAS testing (if required); and<br>-Contamination Testing. |

Initial cost estimates for the project were based on the design of 74 stations. **Figure 2** below, shows the estimated site investigation level breakdown versus the actual breakdown.



**Figure 2 Estimated vs. Actual Investigation Levels**

The final breakdown reflected changes in design methodology and a move from providing capital-intensive physical storage solutions such as emergency storage tanks to providing electrical and mechanical solutions such as generators and bypass arrangements.

### Contamination Investigations

In order to streamline the investigation and design component of the project, environmental sampling and analysis was incorporated into the geotechnical scope of works. The main objective of conducting environmental sampling and analysis as part of the geotechnical investigations was to provide waste classification data for material to be excavated and disposed of off site as part of the upgrade works. In addition, the environmental sampling and analysis allowed for a preliminary assessment of potential site contamination issues, however it should be noted that detailed assessment of individual pumping station sites for the given land use and evaluation of potential human health risks were beyond the scope of the investigations and could potentially have led to very complex site issues.

The scope of contamination sampling and testing was developed in general accordance with the 1999 NSW EPA Solid Waste Guidelines and included testing at least sample of fill material and one natural soil sample for the following analytes:

- Heavy Metals (Arsenic, Cadmium, Chromium, Copper, Nickel, Lead, Zinc and Mercury);
- Total Petroleum Hydrocarbons (TPH);
- Benzene, Toluene, Ethylbenzene, and Xylene (BTEX);
- Polycyclic Aromatic Hydrocarbons (PAHs);
- Organo-Chlorine Pesticides (OCPs); and
- Polychlorinated Biphenyls (PCBs).

The results of these analyses were compared to the NSW EPA Health Based Investigations Levels for Commercial or Industrial Land Use, the Service Station Guidelines and the Waste Classification Guidelines. Samples returning results indicating a waste classification of solid or hazardous triggered additional Toxicity Characteristic Leachate Potential (TCLP) testing. Based on these results a waste classification was developed for the material tested.

## REPORTING AND DESIGN

### Reporting

As is the case in most construction projects, the aim of the geotechnical reporting was to provide the construction team and associated sub-contractors a clear and concise picture of the geotechnical conditions expected for a given site and highlight any potential geotechnical issues or constraints that may be encountered during the construction works. The level of reporting adopted for the individual pumping station sites was again a reflection of the scale of proposed upgrade works and subsequent investigation level. Typically geotechnical reporting for the stations was either in the form of an inspection or investigation report.

An inspection report was generally produced for Level 1 and some Level 2 sites. The inspection report format was developed to provide a concise overview of the potential geotechnical and environmental issues for small to medium scale upgrade works. The basic outline of a typical two to three page inspection report was as follows:

- Site Description and Proposed Works;
- Surface Conditions;
- Ground Profile;
- Geotechnical Hazards and Issues including:
  - Foundation Conditions;
  - Excavation Conditions, Support and Batter Slopes;
  - Acid Sulfate Soils;
  - Chemical Contamination and Waste Classification;
  - Structure Durability; and
  - Groundwater Issues.

A more comprehensive investigation report was generally produced for Level 2 and 3 sites, with the report format reflecting the increased scope of proposed upgrade works and subsequently the more detailed geotechnical investigation methodology. A typical investigation report presented an assessment of the sub-surface conditions at a given site, the results of any testing undertaken as well as a detailed discussion of potential geotechnical and environmental issues associated with the proposed upgrade works including:

- Foundation options/preparation;
- Excavation conditions and support;
- Lateral earth pressures on both temporary and permanent works;
- Uplift considerations;
- Groundwater issues; and
- Waste classification, acid sulfate soil and durability assessments.

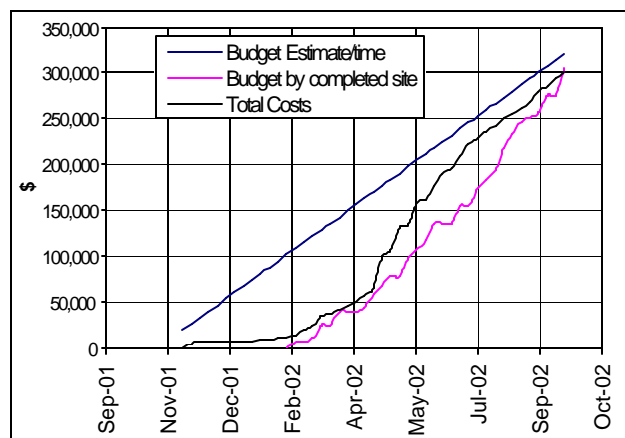
All reports were published in portable document format (PDF) and were distributed and managed via the Bovis Lend Lease information network Project Web. Project Web provided a successful method of on-line document

control, streamlined the document approval process and allowed all project team members easy access to the available geotechnical information.

### PROJECT MANAGEMENT

The project was executed in a number of isolated work packages or tranches with each having its own targets and drivers including cost, schedule and performance. An important feature of the project delivery under an alliance contract arrangement is the measurement of project success. The success of the SewerFix project and thus the shared rewards, relied on the alliance team exceeding best practices in all Key Performance Indicator (KPI) areas; cost, schedule, safety, community, environment, quality and legacy. Under the KPI structure, success is dependent on the whole alliance team attending to cost and non-cost areas with the same degree of priority.

Geotechnical costs were estimated at the proposal stage based on the four investigation levels. These costs were then averaged over the duration of the project to provide a method of tracking investigation costs over time as well as against completed sites. Actual costs were then tracked against this estimated rate of expenditure. **Figure 3** below, depicts actual costs versus estimated costs over the first year of the project to October 2002.



**Figure 3 Geotechnical Cost Tracking**

A total of about \$300,000 was expended on geotechnical and contamination investigation and testing at approximately 63 sites in the first year of the project. This equates to an average price of \$4,800 per site at 2001 prices with the more involved Level 3 sites having an average expenditure of \$6,000.

This method of tracking geotechnical investigation design costs became less realistic when the breakdown of investigation levels changed to include more Level 1 sites and a reduced number of Level 2 and 3 sites. This shift in design methodology resulted in less investigation and design money being spent to complete sites.

The generic investigation levels were also used in resourcing and programming of investigations works.

### CONSTRUCTION

The principal permanent underground structures constructed as part of the SewerFix project were emergency storage tanks. These structures are constructed in order to provide additional physical storage at the pumping stations for utilization in the event of a breakdown or heavy flow situation.

Typically, the smaller emergency storage structures comprised pre-cast, reinforced concrete tanks, while larger structures were constructed in-ground using either a caisson or “bottom-up” approach. The construction method adopted for the larger tanks was dependent on a number of factors including:

- Subsurface and groundwater conditions;
- Space and elevation constraints;
- Surrounding land form, adjacent structures and potential instabilities;
- Site budget and construction schedule;
- Community issues and aesthetics; and
- Environmental issues including contaminated and acid sulfate soils.

**Table 2**, below summarises typical construction approaches used for emergency storage tanks.

**Table 2 Construction Options for SewerFix Sites**

| Option            | Advantages  | Disadvantages   |
|-------------------|---|---|
| Caisson Structure | -Combines permanent and temporary works;<br>-Allows for “wet” excavation;<br>-Reduced risk of base liquefaction;<br>-Can be low cost;<br>-Minimal excavation footprint. | -Irregular ground profile can result in uncontrolled sinking and tilting;<br>-Ground loss and inflow if constructed “dry” below the water table;<br>-Requires a semi-uniform rock level for seating; and<br>-often poor groundwater cutoff. |
| Sheet Piles       | -Provides good groundwater cutoff;<br>-Can be vibrated in or “silently” installed.  | -Dewatering may be required;<br>-Driving problems in blocky fill or talus material;<br>-Careful dewatering to avoid base liquefaction and settlements.  |
| Secant Pile       | -Combines temporary and permanent works;<br>-Can use piles uplift capacity;<br>-Compressive arch effect of piles provides lateral support.                              | -Capital and labour intensive;<br>-Good workmanship required for water tightness;<br>-Large excavation footprint required.  |
| Shoring Boxes     | -No permanent works;<br>-Low capital cost;<br>-Widely available; and<br>-Specialised plant not required.  | -Large excavation footprint;<br>-Limited to small excavations;<br>-Internal bracing limits access to the excavation;<br>-Minimal groundwater cutoff;<br>-Potential for ground inflow.   |
| Open Cut          | -Easy to construct;<br>-Specialised plant is not required.  | -Large excavation footprint required;<br>-Limited safe access to excavation;<br>-Disposal of excavation material;<br>-Limited to shallow excavations.   |

In addition, rock bolting and shotcrete support was implemented for deep emergency storage tank excavations in rock to allow tank formation.

### Geotechnical Involvement

Due to the structure of the SewerFix alliance contract, geotechnical input was not limited to the design phase of the project. Geotechnical involvement in the form of foundation inspections and excavation stability/shoring assessments continued throughout the construction of the pumping station structures. This involvement provided an excellent opportunity to ‘test’ the geotechnical assumptions made during the investigation of each site and further refine the site-specific geotechnical models. This experience enabled confirmation of design assumptions and better control of construction risk, nomination of shoring and temporary works requirements, information which was in turned used to modify the methodology for the remaining site investigations, creating a ‘feedback’ loop rarely seen in typical design and construct projects.

### PROBLEM SITES AND LESSONS LEARNT

**Table 3**, below comprises a list of the more geotechnical challenging pumping station sites and a summary of the relevant geotechnical issues:

**Table 3 Problem Sites**

| Site # | Location      | Description of Works   | Geotechnical Issues  |
|--------|---------------|--|--|
| SP0477 | Lidcombe      | - Caisson construction   | - Minor Ground inflow  |
| SP0820 | Blaxland      | - Caisson construction   | - Uneven rock level<br>- Groundwater inflow<br>- Ground loss around caisson                      |
| SP0515 | Wombarra      | - Caisson construction   | - Slope instability<br>- Talus material  |
| SP1129 | Millers Point | - Sheet piled excavation<br>- Microtunnelling<br>- Hand excavated shafts | - Subsurface gasworks structures<br>- Dyke<br>- Varying sandstone level<br>- Highly contaminated |

The above sites highlighted some important generic geotechnical issues for pumping station sites including:

- The need for adequate site investigation for caisson constructions, including a good idea of rock and soil profile and groundwater conditions;
- The provision of adequate resources (both monetary and labor) for geotechnical site investigations at pumping station sites to avoid knowledge gaps and construction complications; and
- The benefits of ongoing geotechnical involvement in the construction process to help manage any ground related problems that may arise.

### CASE STUDY – SP1129, Millers Point

#### Introduction and Scope of Works

Site SP1129 is located on Hickson Road, Millers Point. The upgrade works for this station included:

- Construction of a new pumping station (SP1129);
- Installation of all associated pipework and connections;
- Decommissioning of existing stations SP0059 and SP0013 due to their location within commercial and residential development sites.

The scope of works at SP1129 included three main aspects:

- Construction of SP1129 using a top-down approach in combination with a sheet piled excavation;
- Microtunnelling approximately 500m of pipework beneath Hickson Road and construction of three associated transition pits; and
- A combination of hand excavated and microtunnelled connecting pipework connecting the new station to the Kent street network above.

### Site Geology and Geotechnical Issues

Hickson Road is situated on the edge of reclaimed land overlying Hawkesbury Sandstone. Previous investigations conducted in the area suggested that Hickson Road is located at the base of a former sandstone quarry while the adjacent reclaimed area comprises a mixture of reworked alluvial material and man-made fill. A small dyke (<2m wide) strikes approximately east west across the site.

A number of significant geotechnical issues were encountered at the site. The area was historically used as a gasworks and subsequently a number of sub-structures including gas holders and tar tanks had been excavated into the sandstone bedrock. The sites industrial history also resulted in the soils, rock and groundwater underlying the area being heavily contaminated.

### Geotechnical Investigations

The geotechnical site investigation for this site included the following aspects:

- Initial desk study of available geological information;
- Drilling two boreholes (one cored) at the proposed location for the new station;
- Drilling five boreholes along the diameter of the underground tar tank in order to establish its size and exact location; and
- Drilling eight cored boreholes along the length of Hickson Road following the proposed microtunnel alignment.

The geotechnical investigation was carried out in phases in order to adequately address the external issues posed by such a complex and sensitive site.

### Problems Encountered

A number of problems were encountered at site SP1129 that consequently refined the process of geotechnical site investigation. These problems included:

- Varying rock level encountered at the new station location. Two boreholes and only limited cored information proved insufficient detail for sheet pile and excavation design.
- Sandstone encountered at the station location was found to be more fractured than suggested by borehole information. This created the need for additional excavation support and stability problems around the microtunnel entry points. A large proportion of the defects were vertical or near vertical and thus were not picked up in the vertical boreholes.
- Problems encountered in microtunnelling the last section of connecting pipework. Sandstone encountered had a higher proportion of clay than expected. In addition, microtunnelling was ceased in an area of soft/clayey material potentially an infilled underground structure or dyke feature.
- Based on the experience gained from this project, a minimum of one borehole in each corner of the proposed underground structure should be adopted for pumping station site upgrades. This number should be increased if significant differences in ground profile are encountered or a caisson construction method is chosen.
- The generic contamination and geotechnical sampling and testing methodology developed for the SewerFix project can be easily modified and adopted in similar projects.
- The alliance nature of the project allowed for continued geotechnical involvement through the planning, design and construction phases of the program and promoted a “no blame” approach to design and construction.

### Lessons Learnt

SP1129 and some of the construction problems encountered there provided a method of improving and tailoring major geotechnical investigations for pumping station sites. The lessons learnt from this site can be summarized as followed:

- Allow sufficient exploration at the proposed station location in order to adequately pick up changes in rock level across the tank structure/excavation. For major structures this should include a borehole in each corner of the structure and potentially one in the middle of the structure if significant differences in rock level are encountered. This is especially important for caisson structures.
- Detailed study of the sub-surface profile in the proximity of the station including any subsurface features, natural or man-made.

### SUMMARY AND CONCLUSIONS

The multi-site SewerFix project provided a unique opportunity for developing a systematic approach to the geotechnical input on sewage pumping station upgrade sites throughout the Sydney metropolitan, Blue Mountains and Illawarra regions. This approach can be tailored to similar, multi-site infrastructure facilities. The main geotechnical features of the project can be summarised as follows:

- The investigation methodology involved grouping the sites into investigation levels (0-3) depending on the proposed scope of upgrade works. This investigation level was then tied into a standard scope of geotechnical and environmental sampling and analysis. Standardised reporting for the project again reflected the level of investigation adopted for each site.
- Average geotechnical investigation cost for the first year of the project was approximately \$4,800 per site at 2001 prices. The more complicated Level 3 sites had an average expenditure of \$6,000.

### ACKNOWLEDGEMENTS

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