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A Permanent Wellpoint Scheme for the Control of Saline Groundwater

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SUMMARY A case study is presented which covers the investigation, design, construction and commissioning stages of a permanent wellpoint scheme for the extraction of highly saline groundwater. Most wellpoint schemes are temporary installations. Excess system capacity is usually provided to ensure rapid response, and design is frequently based upon minimal information with extensive adaptation and on site tuning being necessary. The scheme described herein however was required for permanent operation and this necessitated that all aspects be designed for maximum economic efficiency and life and that they be specified in full detail to permit construction by contract. The investigation, modelling and design were therefore unusually thorough. This paper thus illustrates several general principles and techniques for wellpoint scheme design and construction, and presents them in the context of a unique project.

1 INTRODUCTION

The wellpoint installation studied in this paper is located at Lake Victoria in the south west corner of NSW. It is an unconventional application of a wellpoint installation in that it is a salinity control scheme for the River Murray.

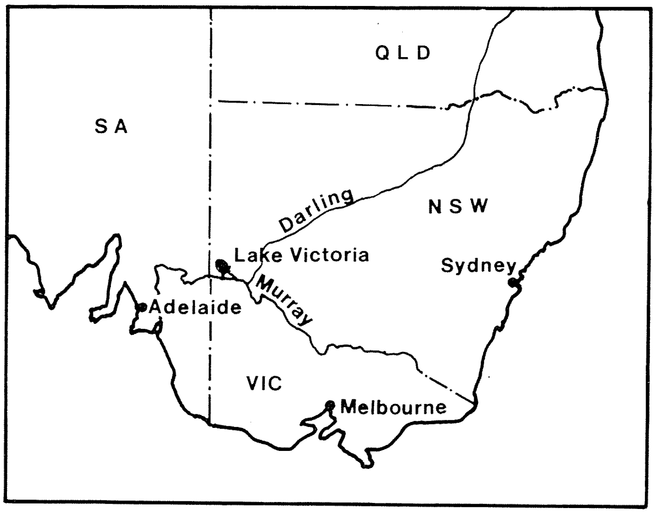

Figure 1 Locality Plan

Lake Victoria is the cause of the salinity problem in the area. The lake was a natural lake which has since been converted into a massive off-stream storage for the River Murray by raising its top water level. Freshwater stored in the lake forces salty groundwater in the sands beneath the lake towards the Rufus River.

Rufus River is used as the discharge channel which returns water stored in the lake back to the River Murray. Although Rufus River is only 3 km long the natural groundwater salinity adjacent to it is so high and the groundwater inflow rate is so large that the channel picks up some 200 tons of salt per day. The salt problem is thus both severe and localised and therefore amenable to an engineering solution.

The flat terrain and shallow groundwater of the river flood plain led to the selection of a solution based upon lines of wellpoints along each side of the Rufus River. Using just 4 centrifugal pump sets, 4000 m of wellpoint lines can effectively intercept the groundwater flows moving from the lake to the river.

The interception scheme, known as the Rufus River Groundwater Interception Scheme, was funded by the River Murray Commission at a cost of $3.3 million. The scheme was commissioned late in 1983.

2 INVESTIGATIONS

2.1 Identifying the Problem

The increase in salinity of the River Murray as it passed Lake Victoria had been identified by salt content measurements of the river over several years. Groundwater inflows were clearly the cause, but before any remedial scheme could be devised, a better understanding of the location and intensity of these inflows was necessary.

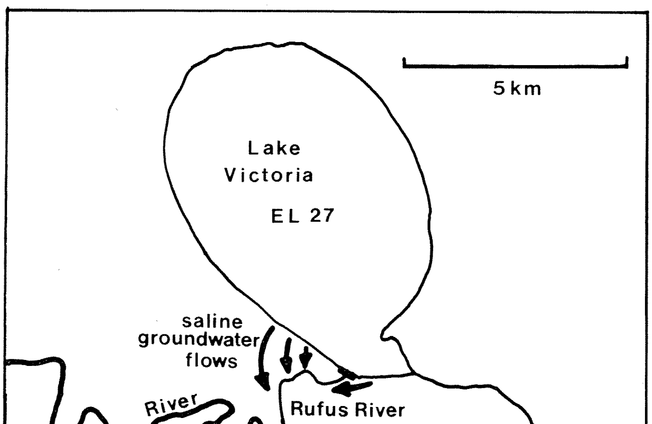

Figure 2 Saline Groundwater Flows

Field investigations undertaken included the measurement of the geometric and hydraulic properties of the aquifer, groundwater contours and groundwater salinity distribution. Several techniques were used.

2.2 Geomorphological Studies

A geomorphological study was conducted early in the investigations. Both the river flood plain and the surrounding country were studied for areas of similar surface level, soils, vegetation etc. A map was then prepared on which former lake bed deposits, point bar systems, several phases of river terrace, recent sand dunes and older mallee system soils were plotted. This work permitted an initial estimate to be made of the soil conditions at any location based on established geological knowledge of the Murray Valley.

2.3 Shallow Trial Holes

A network of shallow trial holes was drilled, generally using a percussive technique with disturbed bailed samples. The holes were 10 to 20 m deep.

A small diameter PVC pipe observation well with a slotted screen for the bottom half metre, was installed in each of these holes to permit pumped groundwater samples to be taken and to enable long term monitoring of groundwater level fluctuations. Fluctuations in groundwater level are quite large due to the cycling of the storage level in the lake and in response to river level changes.

2.4 Deep Test Well

The Rufus River had been identified as the main collector of salt inflows and groundwater removal schemes based on deep wells were being considered. A deep test well was therefore proposed. The drilling revealed however that the sands deeper than 28 m were clayey, and the screen was therefore set at 20 m in materials which apparently contained the coarsest sands. Even so the well, when tested, had a very poor yield and failed to draw water from the near surface soils. It was later realised that these surface soils were more permeable than the soils at screen level and were also partly isolated by thin clayey layers.

2.5 Undisturbed Sampling

Undisturbed tube samples were taken to better understand the nature of the poor yielding coarse sands found between 12 and 20 m. In these undisturbed samples it could be seen that a small proportion of clay was present as a very low density sludge or floc suspended in the saline groundwater. This clay was thus having a significant effect on the permeability of the coarse sands and was considered to be the initial cause of low yield from the deep test well. In contrast the medium sands less than 10 m deep were comparatively clean, and simple pump tests had shown that these sands yielded water quite freely. The clean medium sands were therefore more permeable than the coarse sands containing clay floc. The importance of good sampling to identify the structure and minor components of a soil cannot be overemphasised for this type of work.

The idea of using a permanent wellpoint installation screened in the medium sands at 10 m was thus conceived.

2.6 Groundwater Salinity Mapping

The saline groundwater in the region is the remnant of an ancient inland sea. Its salinity is therefore up to twice that of sea water and is generally uniformly distributed.

In the vicinity of Lake Victoria however there are clearly defined zones where the saline groundwater has been displaced by fresh water seeping from the lake. In some zones the displacement has progressed completely to the Rufus River and no saline groundwater inflow problem remains. These zones are said to be "flushed", although saline groundwater may still be present in the deeper, less permeable sands.

Careful mapping of the groundwater salinities was therefore required, both laterally and vertically, to optimise the location of the wellpoint lines. The salinity data was obtained by pumping samples from the small diameter observation wells installed in each trial hole. The well screens were initially set at full depth, pumped, and then simply pulled up half a metre and pumped again.This technique showed up remarkable variations in yield, salinity and colour over very short increments and (when the yield was adjusted for initial water depth and applied suction) it provided useful comparative permeability data.

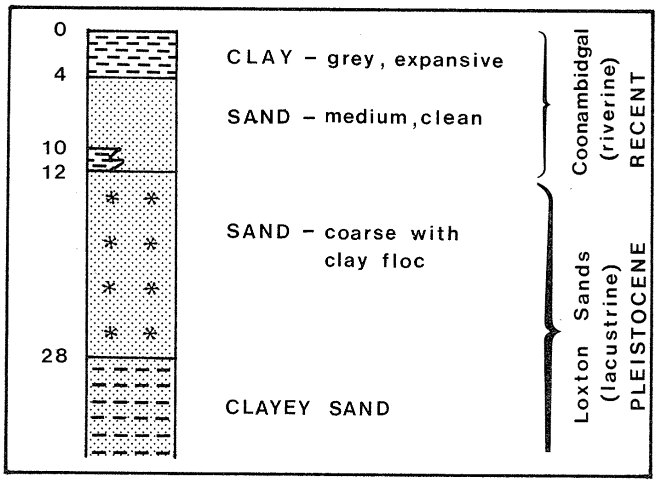

Figure 3 Typical soil profile

2.7 Corrosion and Clogging

The stainless steel screen of the deep test well was removed one year after a single ten hour pump test had been run. It was found that the gravel filter pack had been clogged and cemented to the screen with a carbonate deposit. This alarming discovery initiated an intense study of the clogging potential of both the groundwater and the components of the proposed system, as any susceptibility to clogging would render a permanent installation totally impractical. The groundwater was analysed and found to be saturated in calcium carbonate and dolomite, advice could not be given however as to exactly what conditions would initiate precipitation and what form the precipitate would take.

A test well with a fibreglass screen was pumped for three months and later removed. No signs of reduced pumping efficiency or physical clogging were evident. The clogging of the deeper well was therefore considered to have been aggravated by electrochemical reactions on the metallic well screen.

In Victoria a saline groundwater extraction scheme had been operating for one year using both deep single wells and shallow wellpoint groups with PVC screens. No deposition of precipitates or loss of efficiency had been noticed in the suction side of either the wellpoint groups or the wells, but regular removal of an iron oxide gel deposit in the rising mains was required. It was considered that the deposits in the rising mains may have been initiated by turbulence in the pumps or by air leaks at the pump glands causing oxidation of the water.

The risks of corrosion and clogging were therefore assessed to be manageable by ensuring that all fixed components were of inert or corrosion resistant materials, that care was taken to eliminate all air leaks on the suction side of the wellpoint lines, and that facilities for mechanical and chemical cleaning of the wellpoint screens and rising mains were incorporated in the design.

3 DESIGN

3.1 Design Summary

The design task facing the geotechnical engineer at Rufus River was essentially one of determining the yield from the wellpoint lines and their most efficient location.

Two factors combined to considerably simplify this task. One was that the aquifer had been shown to be shallow, therefore a line of wells placed across any groundwater flow path could be guaranteed to intercept all the water passing along that path. The wellpoint lines could therefore be located some distance back from the Rufus River where a relatively short length of line would protect a long stretch of the River. The second was related to the permanent nature of the scheme in that it was not critical for the required drawdown be achieved rapidly. This reduced the peak yield required from the lines, indeed, modelling and preliminary tests have shown that a satisfactory response time can be achieved by a wellpoint scheme with a peak yield only 25% greater than the expected mean operational flow.

3.2 Tools, Techniques and Lessons

The lessons that are outlined or implied in the above design summary were not so simply learned in practise. The tools and techniques used for the Rufus River design study and the lessons learned from it are therefore presented below for the benefit of other geotechnical engineers faced with the design of dewatering installations.

3.3 Computer Modelling

3.3.1 The program package

By far the most useful tool available to the authors (who are not computer fanatics) was a very user oriented yet comprehensive and powerful computer program package for setting up finite element models of groundwater problems.

Five different models were ultimately required to illustrate and test the sensitivity of various aspects of the design. A single model with sufficient resolution to show all aspects simultaneously would have been immense.

In the following sections the purpose, results and limitations of each of the five models is discussed, though not necessarily in the order in which they were studied. The modelling, like the rest of the investigation and design process of this somewhat unique scheme, was an iterative process.

3.3.2 Individual wellpoint model

The maximum suction that can be applied to a wellpoint is limited. It was therefore necessary to understand in some detail the suction vs yield performance of a wellpoint for a range of possible aquifer properties. A simple axisymmetric vertical slice model was set up to describe this situation.

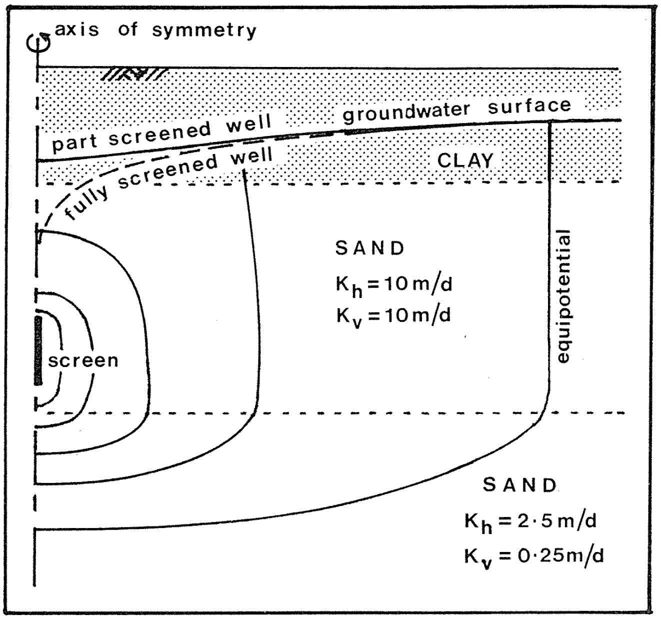

Figure 4 Individual wellpoint model

The model confirmed that a reasonable working yield could be achieved, within the suction limitations, even for the worst aquifer configuration expected.

A further insight obtained from this model is that the shape of the depression in the groundwater surface around a wellpoint is not the classic drawdown "cone" but a shallow "saucer". The cone can only develop for a well which is screened for its full length. Most wells and all wellpoints are screened only for their lower portions. The difference between the two groundwater surface shapes extends only for a radius of 1.5 times the depth to the screen however.

The interaction of adjacent wellpoints and the one-sided inflow from Lake Victoria could not be directly accounted for in this axisymmetric model.

3.3.3 Wellpoint line strip plan model

To check the interference effects between wellpoints in a line and to determine how much water might bypass the lines between the wellpoints, a simple quasi-three-dimensional plan model was set up of a strip of aquifer between a pair of wellpoints. Advantage was taken of the symmetry of the system to minimise the extent of the model, as shown in Figure 5. For simplicity it was assumed that the wellpoints were screened for their full length and that they fully penetrated the aquifer.

The model showed that, for the proposed wellpoint spacing and distance from the Rufus River, the wellpoints fully interferred at the proposed working yield and no groundwater bypasses the line. The most efficient interception occurrs if the mean drawndown level along the wellpoint line is just below the adjacent river level.

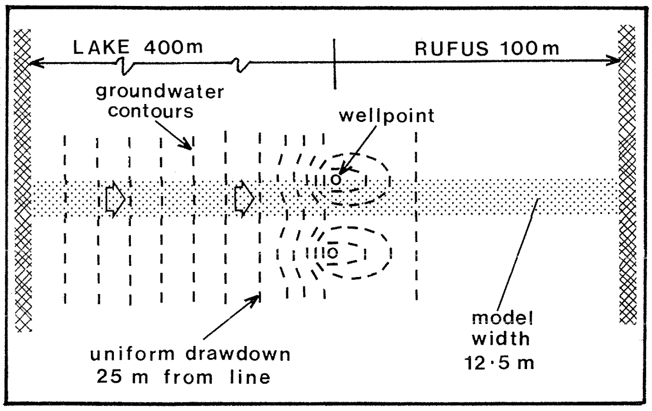

Figure 5 Strip plan model

3.3.4 Wellpoint line cross-section model

A cross-section model (Figure 6) was prepared to determine how effectively screens set at 10 m depth could intercept the total groundwater flow passing through both the upper and lower aquifers.

Several cases were tested, both with and without a clay layer just below the wellpoint screens. Varying degrees of anisotropy (the ratio of horizontal to vertical permeability) were also introduced for both the upper and lower aquifer.

The main assumption made in this model was that the line of wellpoints was equivalent to a continuous adit, however the two previous models had shown this assumption to be reasonable.

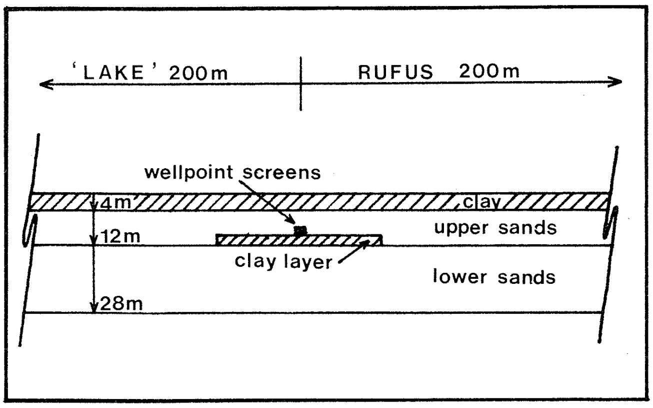

Figure 6 Cross-section model

The results showed that the wellpoint line will intercept most of the groundwater attempting to flow into the Rufus River even under an extremely adverse aquifer configuration. This is due mainly to the shallowness of the aquifers compared with the large distance from the lines to the Rufus River.

3.3.5 Scheme plan model

The largest and most complex model used was a plan model of the whole scheme. (see Figure 7) It used 250 nodes to simulate the transformed aquifers and the relevant boundary conditions.

The model was calibrated, without the wellpoint lines, to reproduce the groundwater contours observed in practise. Calibration was achieved by adjusting the boundary potentials (which represent the lake, rivers, billabongs etc). The salt loads entering the Rufus River were then calculated using the groundwater inflow rates computed by the model and the groundwater salinities measured in the field. The calculated salt loads were compared with salt loads actually measured in the Rufus River and a minor adjustment was made to the adopted permeability values which had been derived from insitu tests.

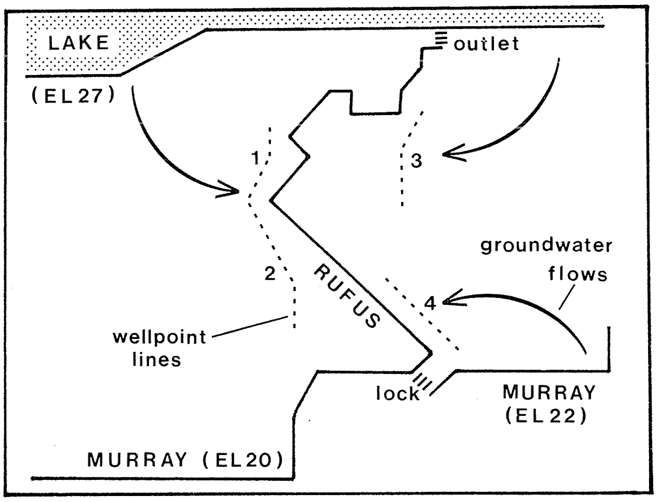

Figure 7 Scheme plan model

Lines of wellpoints were then introduced with the drawdown along the lines set to a level just below the level of the adjacent stretch of the Rufus River. The lake and river levels were set to their worst conceivable limits for salt inflow, and the length and location of the wellpoint lines was adjusted to give the maximum protection to the Rufus River using the minimum length of line. The wellpoint line flows resulting from this model were taken as the design flows for the scheme.

The modelling task was simplified by transforming the three different sand aquifers applying to this model into one equivalent aquifer, previous results having shown that this was not an unreasonable simplifying assumption.

3.3.6 Transient modelling

All of the foregoing models were run only for a steady state solution, the program however permits the study of transient groundwater conditions.

Although it is not critical for this scheme to achieve its protective effect rapidly it is desirable to know the order of the time taken to respond to start up and other changes to the system. Several transient runs were therefore made on the scheme plan model and the strip plan model.

These analyses showed that, for an aquifer confined by the surface clays, the time taken to achieve adequate protection would be of the order of one week to one month. This time delay was of the same order as predicted from pump tests on individual investigation wells and agreed with the results of the two day pump tests on the full wellpoint lines. Where the aquifer is not fully confined, or becomes unconfined during pumping, the response time is longer as water is gradually released from storage. At the time of writing it has yet to be confirmed by extended operation of the full scheme.

4 WELLPOINT CONSTRUCTION DETAILS

As previously mentioned it was essential that the materials on the suction side of the system were inert. It was also important that the possibility of air leaks into the vacuum lines was virtually eliminated. PVC pipe was chosen for all components of the wellpoint system including the slotted screens and the long suction manifolds. All joints were glued and great care was taken to avoid potential air leaks. Flexible PVC helicoil suction hose was used for the cross connections from the wellpoints to the manifold. This flexible connection accommodates the differential movements which will occur between the suction manifold and wellpoint risers when the usually dry, expansive surface clays are saturated during times of flood.

The individual wellpoints are not provided with valves although each wellpoint has an inspection cover at the surface to enable chemical treatment or "swabbing" of the screen should it become necessary, and also to provide access for plugging individual wellpoints in order to "tune" a line.

Installation of the 178 wellpoints, 37 observation wells and 4 km of 150 mm suction manifolds was undertaken by contract. The wellpoints were installed using a 200 mm sand casing which was jetted to full depth after predrilling through the cohesive surface soils. This technique was extremely rapid. The whole contract for the wellpoints, manifolds, cross connections, testing and observation wells was completed in 12 weeks.

The suction manifold was laid and tested prior to the wellpoint installation so that it could be used to supply the jetting water.

After installation each of the wellpoints was individually developed and a yield test done. At a vacuum of 95 kPa the typical yield was 2 L/s compared to a required working yield of 0.4 L/s. Only 4 of the 178 refused to yield because of low permeability soils at the preselected screen depth.

No fully satisfactory test for air leaks could be devised, bearing in mind that even a pinhole would be highly undesirable. Well thought out and tested design details and great care during construction were the best safeguards. The manifolds and blanked off cross connections were however tested under pressure. In operation, minor air leaks could be heard quite clearly as a gurgling sound emanating from the suction manifold near to the leak.

5 PUMPING STATION OPERATION

The layout of each of the four wellpoint pumping stations is shown schematically in Figure 8. The main centrifugal pump has a capacity of up to 20 L/s. The 2.2 kW vacuum pump is of the water ring seal type and serves to prime the system, remove any gases which come out of solution, and facilitates the automatic control of groundwater drawdown.

The control target is that there be a flat grade on the groundwater between the wellpoint line and the Rufus River. Excess groundwater withdrawal is tobe avoided to minimise both the cost of pumping and the load on the evaporation basin.

Control is achieved by setting the vacuum relief valve to correspond to the required groundwater drawdown level. The vacuum relief valve will bleed air into the 2 m^3 vacuum tank at its pre-set pressure and thus control the maximum suction which can be exerted on the groundwater. The two probes detect the water level in the vacuum tank and switch the fixed capacity main pump on (upper) and off (lower). If the groundwater level is high the main pump will run continuously. If the groundwater level is near target the main pump will cycle on and off to balance the groundwater inflow arriving at the wellpoint lines from the Lake. The solenoid valve isolates the vacuum relief valve to permit re-priming when the main pump is off.

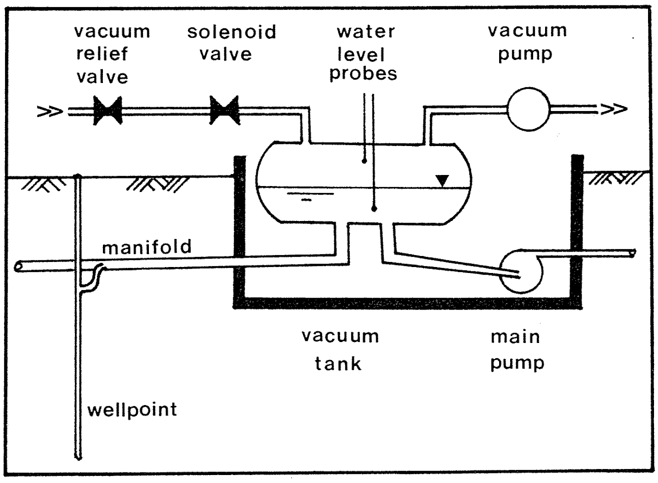

Figure 8 Wellpoint Pumping Station

Initially the performance of the scheme will be monitored by a network of 137 groundwater level observation wells. Ultimately monitoring will be restricted to a few critical wells.

6 CONCLUSION

Wellpoint installations may be economically used for the permanent control of groundwater. To achieve the required economy in construction and operation however, more than the usual attention need be paid to the design and specification of the system. A powerful and easy to use tool to help the design task is a well written finite element groundwater modelling program. The particular asset of such a program is its ability to cheaply test sensitivity of the proposed installation to any nominated parameter, and thus make the best use of available field data and direct the course of further investigation.

Highly saline groundwaters demand not only the use of inert materials throughout the installation but also that measures be taken to avoid chemical deposition. In particular air leaks must be eliminated to prevent oxide precipitation.