DEPARTMENT OF MINES
SOUTH AUSTRALIA

GEOLOGICAL SURVEY
ENGINEERING DIVISION

OVERSEAS STUDY TOUR, AUGUST - OCTOBER, 1975

ISRAEL, FRANCE AND UNITED STATES

by

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GEOLOGIST

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ABSTRACT

A study tour of water resource planning, development and management in Israel, France and United States has shown the need for geologists involved in groundwater hydrology to familiarize themselves with aquifer modelling and computer techniques. At many of the areas visited hydrogeological problems were being solved by use of complex mathematical expressions easily handled by computer. Advantages are that answers may be obtained using a minimal amount of data and by approximating parameters where these are unknown. After calibration of models, sensitivity tests can show whether or not actual field measurements are required which in many instances are time consuming and costly.

Amongst other recommendations are the proposals that alternative methods to drilling be tried to obtain aquifer parameters e.g. use of tracers, chemical analyses and isotope measurements. Where drilling programmes are necessary, they should be vetted to see that maximum information is obtained for minimal cost. In addition, a review of the whole Departmental observation well network is suggested so as to achieve optimum benefits from a very time consuming but necessary undertaking.

Future trips should be programmed so that an individual has more time in one particular organization and can work on a specific project. This is preferable to visiting a large number of organizations and talking with a number of specialists on unfamiliar subjects. There is often insufficient time to fully appreciate more detailed problems associated with each subject before moving on to the next locality.

INTRODUCTION

During August to October, 1975 the author, accompanied Mr. P.J. Manoel, Planning Engineer of the Engineering and Water Supply Department on an overseas tour of Israel, France and portion of western United States. The purpose of the study tour was to gain some expertise in exploration, development and management of water resources with specific regard to groundwater.

The tour followed an earlier one by Shepherd, Killick and Tuckwell of the Water Resources Branch of the Engineering and Water Supply Department who examined groundwater management and legislation in Israel, Europe and United States. This trip was arranged by the above mentioned Branch and the itinerary is outlined in Manoel and Williams (1977). Six weeks were spent in Israel with Tahal (an organization responsible for planning the development of Israel's water resources), 1 week in France with the Bureau Recherche Geologie et Mineralogie (hereafter B.R.G.M.), 1 week with Battelle (a consulting firm who carry out work on various aspects of water resources) at their Northwest Laboratories, Richland, Washington and 2½ weeks in California visiting Montgomery Engineering (consulting engineers in the field of water resources), various institutions and field stations concerned with hydrology and the California Department of Water Resources.

ISRAEL

31/7/75 to 12/9/75

A detailed discussion of water resource development in Israel is considered unwarranted as this has been adequately covered by others such as Webster (1971) although this is now partly out of date. Rather a brief summary is given, followed by selective comments on various aspects of interest.

<u>Water Resources Agencies</u>

Firstly, all water resource exploration, planning and management is carried out by Tahal Consulting Engineers (hereafter called Tahal), a government organization predominantly comprised of engineers with a few geologists and geophysicists, mathematicians and computing staff. Tahal consults in many developing countries - particularly in the fields of water resource exploration and development. In addition within the organization research is conducted into many aspects of water resources such as artificial recharge with storm water and treated sewage effluent, cloud seeding, long term salinity build-up problems in irrigation areas, local pollution problems, saline inflow contamination of usable water resources and optimal use of water in urban consumption.

Water supply and effluent disposal come under the auspices of Mekorot Water Company. The whole supply network of wells, pipelines and surface storages is completely integrated. The majority of the nation's water resources occur in the central and northern parts of the country and a large 2.7 m (108") pipeline (part of the National Water Carrier system - Fig. 1) is used to bring water to the more arid south. Mekorot carry out all their own construction work including well drilling, testing and completion, though in liaison with Tahal.

Water resource legislation in Israel comes under the Ministry of Agriculture. Responsible to the Minister is the Water Commissioner who heads a group of departmenta responsible for water allocation (i.e. quotas, rationing, licencing, well permits), efficiency and economics of water usage, hydrological surveys and drainage.

Other agencies or institutions involved with water resources are principally dedicated to pure research and teaching. These include the Groundwater School within the Hebrew University of Jerusalem, the Negev Institute for Arid Zone Research at Beer Sheva, various sections of the Weizman Institute of Science at Rehovot, and the Volcani Centre, Institute for Soil and Water, south of Tel Aviv. The Geological Survey of Israel have only a small section dealing with groundwater and tend to specialize on minor problems or research topics.

Hydrology

Rainfall in Israel varies from 900 mm in the north to 50 mm or less in the south and falls only during November to May (Fig.2). Most of the usable water resources (i.e. salinity <1 000 mg/1) occur in the northern half of the country. Usable surface water (after evaporation and runoff loss) is about 500 million cubic metres (hereafter MCM) most being inflow to Lake Kinneret (Sea of Galilee) from the River Jordan. Groundwater adds 1 000 MCM, for a total of 1 500 MCM, being withdrawn from two aquifer systems. The oldest is the Cenomanian-Turonian aquifer - a folded, fractured and fissured limestone which may be confined or unconfined and occurs within the central mountain belt. The other, the younger, is Pleistocene, generally unconfined and comprised of flat lying calcareous sands with some lenticular clay beds and occurs between the mountains and the coast.

Groundwater flow is westward toward the coast west of a divide which more or less coincides with drainage divide at the peak of the central mountain belt (Fig. 3). East of here, flow is opposite to the above, being toward the Dead Sea, and very importantly, to a base level of - 400 m. One serious result of this low base level is the extremely large pumping lifts of over 400 m in wells near the top of the divide such as those which provide Jerusalem's water supply.

Water Well Drilling

About 95% of water well drilling is carried out under the supervision of Mekorot using their own drilling equipment and personnel. Wells may be required by planning engineers in Tahal for either recharge, discharge or exploration purposes. After talking with Mekorot people for only a few minutes, it became immediately obvious we were talking on different scales. Wells in Israel tend to be of much greater diameter and depth than those in South Australia, mostly related to the two base level problem (i.e. almost anywhere in the country, depth to natural water table is near or below sea level irrespective of topography). It is cheaper to drill one deep large diameter well, equipped with a large pump than to drill and equip two small diameter wells. The depths involved vary from 50 to 1 200 m and well diameters from 813 mm (32 inches) to 356-406 mm (14-16 inches) at the bottom of the well.

Preparatory work for new wells - specifications, supervision etc.

The following procedures are typical of those used in preparation of specifications, supervision and completion of a new water well.

(i) Initially, a regional geological survey is carried out at a 1:20 000 or 1:50 000 scale depending on geological data already available. This may not be necessary in some instances. Some months may be required for the survey and costs may be $750 - $1 250 depending on mapping required. Some scout drilling with a Failing 1 500 rig may be carried out especially when the Pleistocene (coastal) aquifer is the target.

(ii) Resistivity depth probes are carried out for prospective and alternative sites to delineate the impermeable base of the aquifer. In many areas these are already available. Some use of gravity and magnetic data is made depending on availability and location (data source usually from petroleum exploration). The Israelis have found good correlation to exist between resistivity and hydrogeologic properties i.e. salinity, porosity.

(iii) A well forecast is made by the geologist concerned. This gives predicted:

(a) purpose

(b) stratigraphy

(c) hydrogeology i.e. salinity, water level, well capacity

(d) casing programme

(e) drilling programme

- in similar manner to our own specifications.

(iv) This forecast or proposal then goes to a committee (No. 1) comprising the following:

(a) 2 hydrogeologists from Tahal

(b) 1 planning engineer from Tahal

(c) 2 representatives from Mekorot

(d) 1 representative from the Israel Geological Survey

(e) 1 representative from the Water Commission

They will approve or disapprove the proposal on the basis of hydrologic regime, planning needs and environmental grounds.

(v) On approval, access roads and a water supply are then provided.

(vi) The proposal is then submitted to another committee (No.2) convened by the Water Commission who discuss the legal aspects of the programme. They then notify the public giving 2 weeks notice before commencement of drilling (i.e. public funds are to be spent - any objections?).

(vii) Drilling then commences under supervision of the proposer. He may only visit the well once a week, unless it is an exploration well where-upon he remains on site. He must present fortnightly reports to committee No. 1. After cessation of drilling, development and well testing, he again reports to that committee who decide on equipment to be used in the well. Finally a licence covering the pumping allocation for the new well is issued by committee No. 2.

Drilling machinery and methods

Percussion drilling - not used a great deal.

This method is generally used with wells that are shallower than 250 m in hard strata and 150 m when in sand. Types of rigs are as follows:-

(i) Walker - Neer - 600 m capacity and originally converted from a rotary percussion rig.

(ii) Cyclone 48 trailer mounted and with a 100 HP Caterpillar engine.

Rotary drilling - most common technique.

(i) reverse circulation

This method is used when well depth is less than 200 m and strata are soft i.e. in the coastal sand and sandstone (Pleistocene) aquifer. Rig type is a Salgitter of German make.

(ii) normal

This method is used when well depth is from 250 - 1 200 m and when strata are hard e.g. in the Cenomanian-Turonian aquifer. The rig type is a Franks Rocket made by Cabot and Co. of the United States and costs $400 000. Cost of a well drilled to an average depth of 700 m including drilling, casing, well testing, acification and preparatory work is about $250 000. For a shallower well, say 100 m, the cost is $24 000. The large costs are due to:

(a) expensive large diameter casing

(b) expensive drilling equipment

(c) large amount of mud and cement (they use petroleum well contractors for this job)

(d) wages - drillers work 12 hour shifts (a full time welder is also on the job)

(e) access costs - they often have to construct their own roads to the site.

Pressure cementing

The Israelis use petroleum drilling techniques for cementing - similar in basic approach but on a larger scale. One important aspect of their techniques is that when cementing upper levels of their wells, they bail the well dry after the cement has set to check for leaks. It should be noted that in many cases, their deep wells are drilled only to the unconfined aquifer. The problem of saline unconfined groundwater overlying fresh confined groundwater is very uncommon in Israel.

One criticism levelled at our practice was the thickness of the cement layer used in normal drilling practice. They thought 25 mm too thin and prefer using 75 - 100 mm.

Gravel Packing

This technique is used for all wells completed in the Pleistocene aquifer. Packs are 75 to 100 mm thick and sometimes consist of two grain sizes. Commonly used sizes are 3 - 5 mm (fine gravel) and 1 - 1.5 mm (coarse sand). They have noticed a decrease in specific capacity using gravel packs but this is apparently not significant and has the advantage of prevention of sand pumpage. Screen sizes and optimum packs are selected from tables (Johnson's) after normal sieve analysis. In many cases they may select these beforehand as the Pleistocene aquifer consists of uniformly sorted sand.

Acidification

The process of acidification of wells intersecting carbonate aquifers has been achieved successfully in Israel. Initial experiments in chalky aquifers did not give promising results but more success was obtained in fractured limestone aquifers, to the extent that all wells intersecting these aquifers are acidified as part of their completion programme. The acid can also remove mud cake and drilling slurry from the well wall and infillings in karstic limestone. To cite an example, one well before acidification had a yield of 123 m^3/hour (2 800 m^3/day) and drawdown of 140 m and after acidification the yield rose to 410 m^3/hour (9 840 m^3/day) with a drawdown of only 80 m.

The process is fairly simple. The mixture is a fixed volume of 30% hydrochloric acid (calculated on well area x aquifer thickness) together with some inhibitor to prevent acid reacting with the casing, antifoaming chemicals and a retardant to slow the reaction down. This is then pumped into the well and allowed to come into contact with the aquifer. Unfortunately, all information on acidification is in Hebrew but if more is required Mr. Simcha Shiloni of Mekorot would be pleased to help (see address, Manoel and Williams, 1977).

The one problem with the process is its failure to achieve much better specific capacity in aquifers with only intergranular permeability. One hydrogeologist I talked with had thought of using explosives to set up a fracture system in this sort of aquifer (i.e. Pleistocene aquifer) and then acidify but had not put his ideas into practice.

The process of acidification has promise only in hard rock areas of the Mt. Lofty, Flinders Ranges area in South Australia although it may be useful in cleaning up mud cake, drilling sludge etc. from well walls in any other area.

Sampling

Sampling procedures are similar to ours. Samples are collected at 3 m intervals, but dried and split into two, one set being kept on site until drilling is complete and the other set being sent to the office for discussion and logging and examination by a micropalaeontologist. They use small rectangular cardboard boxes (35 cm square) with 24 smaller lift out boxes with tags on for writing depth. All sampling is usually carried out by the driller.

Geophysical logging

All wells less than 150 m are logged using a WIDCO portable logger. For deeper wells, larger oil company type logging units are used but only rarely due to the large expense involved. Types of logs usually run are electric and acoustic cf. gamma and neutron. Most wells are drilled with rotary mud techniques so these logs generally give good response cf. the water drilled percussion wells.

Drillers

No official training scheme exists for drillers. They apparently learn through practical experience only and are not recognized as having special qualifications. Pay rates are low but they make up for it by working 12 hour shifts, 5 days a week. Their weekly drilling reports are similar to ours but far less writing is involved. Their time sheets have columns for such work as drilling, running casing, sampling, fishing, setting screens, gravel packs etc. so all the driller has to do is write down hours worked on each specific job.

Observation wells

These are drilled in similar ways but naturally on a smaller scale. All are fitted with well screens (wire wound) if in unconsolidated strata. They have tried injecting aquifers with epoxy resin as used in bonded sandscreens. One well was successfully treated and another unsuccessfully. The time and effort required were too much to warrant further work. Wells are fitted with a welded steel cap in which sits a small plug opened only by a magnet - rendering then reasonably vandal proof. In most cases steel casing is used rather than PVC as it is used as an electrode when logging the well with a resistivity tool - especially in areas where sea water intrusion is a problem and careful definition of the interface is required.

The observation network is checked regularly by a maintenance team and if any require rehabilitation, this is carried out immediately. If it should take more than two days a decision is usually made to drill a new well as costs are comparable and one can never be sure the rehabilitation work will be successful.

Where subaquifers occur e.g. in the Pleistocene aquifer near the coast they have found it cheaper to drill single wells to each rather than drill one large diameter well and complete 4 or 5 smaller ones within it. They make use of existing pumping wells where ever possible. In fact it is law that all wells have some access for water level measurement.

Aquifer well tests

Initial testing of water wells after actual drilling is completed consists of a 1 hour bailer test, examining recovery and water quality at the end of this period. There are two approaches to more detailed testing - each depending on the aquifer type.

Cenomanian Turonian aquifer (fractured rock)

In this situation, prodecures begin with pumping at different rates, with hourly water levels and rates noted. This enables some comments to be made on anticipated pumping rates during the main test and for later production and on water quality, odour, turbidity etc. A normal drawdown recovery test then follows followed by a step drawdown test with either decreasing or increasing pump rates. Normal procedure is to await for equilibrium conditions to be attained and then complete recovery before commencing the next stage (i.e. no time limit). Acidification may then be tried and the various tests repeated to observe any changes in specific capacity etc.

Pleistocene aquifer (unconsolidated to cemented sands)

In this environment, initial testing takes place using a plunger pump to flush the aquifer. They then install a larger capacity pump and pump at very low rates, gradually increasing the rate to somewhere near the desired level (e.g. pump at rates 1 200, 2 400, ...etc m^3/day to finally 7 200 m^3/day) and with gravel packed wells - slowly adding gravel to replace any sand which may be pumped out during development. Once the anticipated rate is reached, water quality and gravel pack stability are checked. Then the normal well tests are carried out as above. A chemist is also on site to take samples for field analysis of pH, H_2S, dissolved oxygen and carbon dioxide and laboratory analysis of other ionic species.

On conclusion of all testing, results are presented to the client (Tahal) by the supervising hydrogeologist (all well testing is carried out by trained technicians). His report gives suggested pumping rates (hourly, daily and seasonal), drawdown levels, pump setting depth, anticipated quality changes etc.

Data accumulation

As mentioned earlier, this is the responsibility of the Hydrological Services Division, the authority of the Water Commissioner. Within this division, there are sections responsible for data collection, processing and presentation (i.e. contour plans, hydrographs etc.) and a small group who carry out some research (e.g. on sea water intrusion to the Pleistocene aquifer).

Collection (ground and surface water)

Observation wells

There are various networks throughout the country the more intense being the one along the coast to monitor sea water intrusion and another around Jerusalem.

(i) Coastal network (Pleistocene aquifer)

Within this network are some 300-350 wells, most dense at the coast. All are 51 mm (2") and are used twice yearly for water level measurement and determination of the sea water - fresh water interface using a resistivity device. Measurements are to the nearest 1-2 cm.

(ii) Jerusalem area

This network consists predominantly of pumping wells with access for a water level probe. Levels are measured 3-4 hours after the pump has been switched off. Again frequent measurement is twice yearly. Samples are collected during summer for A.T.S., chloride and pH determinations.

(iii) Optimization of measurement frequency (network design)

The section responsible for data collection has been investigating the design of optimal observation networks i.e. with a view to obtaining the maximum amount of data for a minimum amount of field time. They considered statistical evaluation of data on a basis of time and space i.e. the possibility of predicting certain monthly values of one well knowing the rest and/or knowing its comparative behaviour with a nearby well or wells. Using each theory, costs of setting up and monitoring a grid could be significantly reduced.

Some of the constraints in such an analysis are

(a) the time interval or frequency of monitoring (one month in this case).

(b) enough well monitoring points must be deleted to eliminate field visits to whole areas - in other words it is all very well to eliminate one well but if a field assistant has to bypass it on his way to another he may as well measure it.

(c) probability coefficients must be applied to this situation and these are difficult to assess.

(d) the benefits compared with the overall cost of the programme.

It is pointed out here that if no control exists on groundwater withdrawal as say in most of S.A., an optimized network would fail with any change in the pumping regime brought about by equipping or abandoning new or existing wells. Despite this however, I feel we should give far more consideration in the selection and monitoring of observation networks.

Springs

There are at least 300 springs measured monthly throughout Israel and others at less frequent intervals. Weirs or flumes are used for most with permanent recorders being fitted to those in areas of exploitation.

Streams

About 100 gauging stations have been set up in Israel, many with continuous water level recorders. Normal current metering techniques are used elsewhere and occasionally indirect methods of estimating flow such as height of flood debris in areas of difficult access. To overcome the problem of not knowing when to go out and gauge - typical in such an activity, the Hydrological Service Division use curves of "reverse cumulative evapotranspiration" together with information on magnitude and duration of rainfall at a particular site and the soil moisture deficit at that site to predict runoff magnitude for an event and whether it is worth going to the field or not.

Processing

All water resource data as they accumulate are punched on to existing files or await punching on to new files, soon to be prepared. There did not appear to be many differences between their system and ours - perhaps we are 12-18 months behind. Tables, hydrographs, rating curves and contour plans can be obtained by computer print out. Programmes for data retrieval in the form of tables,hydrographs, sea water-fresh water interface positions, contour plans and rating curves had only just been or were being introduced into the processing system. One processing technique discussed was that of curve fitting (Spline method) to a set of values to obtain approximations to missing data for use say in potentiometric contour plans. Other information was retrieved for aquifer calibration and forecasting - results of modelling studies carried out by Tahal, etc (see later).

A significant point with this whole system was the availability of retrievable data soon after field measurement. For instance, rating curves, contour plans, forecasted water levels (based on previous months readings) were available within 2 to 3 weeks of the actual field readings.

Groundwater modelling

Introduction

The usage and importance of mathematical modelling of hydrologic systems was probably the most striking feature of the Israeli approach to water resource planning, development and management. Such modelling allows complete quantification of almost all of the country's water resources and provides a very useful tool for predicting effects of droughts, overpumpage, water quality changes etc. Various models are used depending on scale (see Schwarz, 1972 - various):-

(i) a regional scale where

  (a) national water resources are considered as a single groundwater reservoir supplemented by surface water.

  (b) groundwater and surface water basins are treated as separate entities.

(ii) on a local scale where well fields or single wells are considered.

Principles behind aquifer modelling

Aquifer modelling involves division of the area underlain by the aquifer into cells of varying but generally regular shapes and assigning water balance parameters to each. Using mathematical techniques (e.g. finite difference, finite element) and a computer one may then simulate the effect of varying any one of the water balance parameters on the aquifer system. e.g. excess pumpage, drought, artificial recharge etc. The general steps taken say for modelling a single unconfined system are as follows (from the hydrogeologists point of view):

(i) Collection and coding of all well data in a form suitable to punch on to computer file.

(ii) Selection of areal boundaries - this decision depends on whether a whole basin is to be modelled or only part. In the former case, this entails geological input. Boundaries may be aquifer limits, streams, drainage divides or purely arbitrary.

(iii) Division of the area intended to be modelled into cells (squares, rectangles, polygons - depending on mathematical techniques to be used and purposes required).

(iv) Evaluation of water balance components for each cell.

(a) Precipitation - may need to use elevation factor if area not flat as extrapolation between contours is usually not linear.

(b) Infiltration rates, recharge from experiment or approximation (e.g. stream loss per km).

(c) Stream flow - from records which are usually limited. Drain and irrigation channel components of surface inflow and outflow. Spring flow.

(d) Evapotranspiration

(e) Aquifer pumpage

(f) Aquifer properties

(i) potential - routine observations. In areas where fluctuations occur due to large groundwater withdrawals some history of pre- and post-irrigation water levels are necessary to obtain transient state conditions.

(ii) thickness - for later usage in estimating transmissivities.

(iii) storage coefficient (specific yield) - extrapolate on basis of lithology from cells where aquifer tests carried out or where laboratory results are available or use simple empiricisms.

(iv) transmissivity - extrapolate from where tests have been carried out. Use lithology, gradient patterns, specific capacity tests etc. to determine an approximate value. Allowance made for partial penetration - No correction for full penetration.

Once all initial data including estimates are obtained, the model requires calibration. Firstly, the model is run to reproduce groundwater levels - usually in the form of hydrographs. These are compared with the historical data and where differences occur, changes made to the various parameter estimates till closer agreement is obtained (Fig. 4). Initial estimates of T, S or infiltration may have been quite wrong for, say, lack of stratigraphic information or there may be no adequate record of pumping history. As every new year's data accumulates, further calibration runs should be tried to obtain a more representative model. In practice it has been found that close agreement between system and model should be sought only in areas of more intense exploitation. Little time should be wasted in attempted calibration in fringe areas.

During calibration, sensitivity tests are run on the model to see how it is affected by changes in each of the parameters. If it is sensitive to tranmissivity values in one area, it may be necessary to carry out some field investigations. This can be a real money saver in the long term if it can be shown that estimates from available data can be used to adequately simulate the system.

More complex systems may be modelled along similar lines. Techniques are now available to model unconfined/confined and complex confined aquifer systems, sea water intrusion and water quality changes. The latter are much more complex because of mixing processes. All these models require additional information such as confining bed parameters, leakage coefficients etc. and calibration becomes more difficult and time consuming. The complexity depends naturally on data available.

<u>Use of models in planning and management</u>

Once the model is calibrated and good agreement with the true hydrologic system is reached, it becomes a predictive tool for planning and management purposes with the basic purpose being to optimize all operations. Information gained from the model can be in several different forms.

(i) The behaviour of the system under drought conditions can be simulated. The worst situations from random sets of rainfall data as generated by statistical means are used to determine effects on groundwater levels, long term quality, economics etc.

(ii) Development of a groundwater basin can be planned by knowing the pumping distributions which achieve optimal groundwater levels, minimising dangers to the aquifer (see also Hydrochemistry).

(iii) Optimum pumping conditions along the coast to prevent seawater intrusion can be obtained (Fig. 5, 6). In the particular case with the Pleistocene (coastal) aquifer in Israel, a network of collector wells have been constructed along the coast and are pumped at rates to just maintain a seaward gradient.

(iv) Optimum planning of complex water distribution systems involving many pumpage and recharge sites can be achieved (see under next heading).

(v) Optimum management of reservoir storage can be achieved i.e. Lake Kinneret. Modelling of this resource from both a water and salinity budget point of view enables better protection of this valuable resource representing one third of the country's total water resources. Proper control on storage head is required as saline springs flow into the lake at its bottom. One theory on their origin implies if heads are lowered below a critical level, it will increase flow to such an extent that much of the remaining resource will become too saline for human consumption. Many saline spring flows around the edge of the lake are collected and diverted via a concrete channel to the River Jordan at the downstream end of the lake.

Comments

Modelling of hydrologic systems is a must for planning and management purposes. Without them, the job is virtually impossible. Close co-operation between geologists, engineers, mathematicians etc.is essential if modelling is to be a success as all have their role in such investigations.

Artificial recharge

Artificial recharge is practised economically in Israel in many ways. Storm water runoff, Lake Kinneret water, and treated sewerage are all utilized although the latter is in early trial stages. In all cases, recharge of unconfined aquifers is practised as available storage, volume and recharge rates are much greater than with confined aquifers. Some details on each method follow.

Stormwater runoff

Stormwater from emphemeral streams in the low lying foothills adjacent to the central mountain belt is diverted by means of weirs and open channels to sand dune areas on the coastal plains. Here, several ponds have been excavated, the first to act as a settling basin from which the low turbidity water (most important should be less than 1-200 mg/l total load) is channelled to the others known as spreading basins. Initial infiltration rates may be as high as 1-3 m/day but drop off as clogging becomes serious. At the end of each season, the spreading basin floor is disc ploughed to break up any algal mat and clogged zone. About every 5 years they scrape the top 5-10 cm of the surface to remove the build up in algae and fines. A most interesting point at one site (Nahale Menashe - Fig. 7) was the practice of excessively lowering the water table to create a sink before the rainy season and thereby increase recharge.

Application of this technique to desert streams so far has been unsuccessful as the extremely high sediment load (10-50 000 mg/l) caused immediate clogging. Settling reservoirs are a must if this is to be successful in that environment.

Lastly, abandoned limestone quarries in the foothill areas are being considered as cheap recharge sites. It is expected that most recharge would take place through the quarry walls as settling would soon clog the floor. Presumably some annual remedial action would be necessary to maintain consistent infiltration.

Lake Kinneret water and groundwater

Water from the National Carrier (of both surface and subsurface origin) is discharged into wells and abandoned sand quarries south of Tel Aviv to counteract development of cones of depression beneath irrigation areas. Infiltration rates of up to 2.5 m/day have been obtained in the quarries. Algal mats resulting from biological matter in Lake Kinneret water are a problem. On the quarry floor however, they can be manually removed at the end of each recharge season. This type of water also causes serious problems in wells. Clogging may also be related to chemical constituents as well as biological and sediment load. Groundwater is preferred for well recharge. Where possible dual purpose wells are used to partially eliminate the clogging problem. Wells that are used for discharge in summer are recharged in winter. The following summer, initial pumping does produce some water of undesirable quality for a few hours but it soon returns to a suitable level. Generally speaking, recharge rates have been found to be about two thirds of discharge rates. A word of caution given was to take care when recharging the unsaturated zone as the Israelis lost a complete 5 m high pump house through land subsidence.

Some studies on mixing between recharged water and natural groundwater have been carried out. In the Pleistocene aquifer they found a mixing ratio of about 1:1 i.e. they must pump twice the recharge volume to reach the original water within the aquifer. Within the Cenomanian-Turonian aquifer the mixing is much better, this being attributed to better porosity and permeability. Using experience with this operation, the Israelis hope to recharge storm water via wells into saline aquifers, recovering the water at a later date. On initial repumping, some water is lost through quality degradation however, the situation soon improves with time.

This whole recharge programme near Tel Aviv is quite complex, with a large number of withdrawal and recharge sites and several sources of recharge water (surface water and groundwater from both aquifers) all integrated within the National Water Carrier system. At one point, the Cenomanian Turonian aquifer is so transmissive, it is actually used as part of the pipeline system - pumping in at one site and withdrawing at another some kilometres away with almost zero drawdown (i.e. behaves almost as a free water surface).

Treated sewage

A large scheme (Dan Scheme) to treat effluent from the greater Tel Aviv area and use it for groundwater recharge and later for irrigation purposes has been proposed and a pilot study has been in operation for several years (at present the effluent is disposed in the Mediterranean). Treatment involves aeration (oxidation), lime clarification,, ammonia stripping and polishing. The product will be pumped to spreading basins to be later recovered via wells after 400 days. The suspended load (5-20 mg/l) in the treated effluent is too high for use in well recharge. One major problem is that the supply is not where the demand really is i.e. the treated effluent may prove too expensive to supply to agriculture some distance from the treatment plant. One answer here is to introduce it into the existing urban system but their Ministry of Health people are yet to be convinced that the treated effluent is safe to use.

An interesting sideline to this has been groundwater monitoring for pollution effects beneath the oxidation lagoons etc. Initially infiltration through the bottom of the lagoons was fairly fast but has slowed down by ten fold due to self sealing effects. Chloride, used as an indicator after 5 years, was the same at the water table beneath the ponds (110 mg/l) as the effluent but 80 m away was 40 mg/l, 160 m away 25 mg/l (all compared to background groundwater value of 10 mg/l). The situation has remained as such for some years now. Filtration in the unsaturated zone here had prevented viruses, bacteria and all but a very insignificant amount of heavy metal reaching the water table.

Hydrochemistry

Routine sampling and analysis

Mekorot has its own analytical chemistry section. Samples for laboratory analysis from new or existing wells are collected by trained personnel from that section. There are fewer problems with distance between the field site and laboratory necessitating special sample treatment in Israel. Most distances involved are from 50 - 150 km. Where field measurements are needed, the laboratory section uses Hach field kits, having found them most reliable. Typical species analysed in the field are dissolved oxygen, carbon dioxide and hydrogen sulphide as well as pH. No special vehicle or elaborate equipment is required as all kits are quite compact. A Hach catalogue is now in Divisional files.

Isopote work

The use of isotopes in hydrological investigations is common in Israel, particularly in research institutions such as the Centre for Groundwater Research at Hebrew University and the

Isotope Research Section of the Weizman Institute and to a smaller extent within Tahal.

Centre for Groundwater Research

Here recent work has concentrated on oxygen, sulphur and uranium isotopes, deuterium and combinations of these. Abundance of deuterium and O^{18} are influenced by altitude. Some work on the proportion of these two isotopes in spring waters has shown their source of replenishment to be at topographic elevations which only exist in the central mountain belt. Work on sulphur isotopes (S^{32}, S^{34}) provided supplementary results to the above although fractionation processes are different.

Lastly uranium isotopes (U^{234}, U^{238}) have been used to estimate the duration of contact between groundwater and an aquifer as fractionation takes place at the boundary. Work in the central Israel region showed different ratios east and west of the groundwater divide indicating different conduit mechanisms probably related to the differing base levels (i.e. older stable Mediterranean sea level cf. very young Dead Sea level at minus 400 m).

Isotope Research Centre - Weizman Institute

Major discussions centred around use of tritium and $carbon^{14}$.

(i) $Carbon^{14}$

This isotope has been used in a project centred along the coastal strip south of Tel Aviv. Groundwater samples were collected from the Pleistocene aquifer along a strip 15 km x 50 km in an attempt to determine residence times. Sampling techniques are standard - precipitating the carbonate as $BaCO_3$ by adding NaOH and $BaCl_2$ under inert conditions (i.e. similar in most respects to CSIRO techniques).

Results showed most groundwater to have residence times of about 150 years, but pockets were located which had residence times of 3 000 years indicating some stagnation within the aquifer probably related to lenticular confining layers restricting groundwater movement. Where age can be defined as greater or less than 20 years by using tritium, C^{14} is also used to determine proportions of young or old water in such mixtures.

(ii) Tritium

Samples analysed for tritium (use glass sampling bottles with spring seals) include rain water from a number of sites (routine), surface water e.g. reservoirs (surface and at depth) and groundwater (sampling only after minimum of 2-3 hours pumping, preferably 24 hours). Some sampling of the unsaturated zone is carried out for specific projects. Tritium has been used in relation to the saline inflow problem to Lake Kinneret - a problem which, if solved, could make considerably more water available for urban and agricultural use. The inflow had been known for some time from straight salinity balance studies but its nature not understood. Tritium studies of the lake water and sediments inferred upward advection through the bottom of the lake. Although unmeasureable, this advection was thought insufficient to provide the amounts of salt required to make up the discrepancy in the salt balance. Rather it was considered likely that the inflow is in the form of large saline springs and recent investigations have concentrated on their identification.

Another specific investigation using tritium has been to identify sources of flow in the River Jordan i.e. to quantify components in terms of previous years' rainfall. Taking a particular sampling point and analysing for tritium, present flow can be split into components as follows.

15% of the flow is due to this years rain

20% ....last ....

30% .... rain falling 2 years ago

enabling groundwater discharge components to be calculated (e.g. something like Prof. Holmes work on the Glenelg River).

Tritium has been used in investigations of the accumulation of nitrate in groundwater beneath irrigated areas in an attempt to determine the means of contamination and its path. No correlation was obtained so better success is being sought by looking at isotopes of nitrogen and oxygen in fertilizer and the aquifer system itself.

One of the important points arising from discussions with researchers at the Isotope Research Centre was sampling in aquifers where stratification existed. They, nor we, could not make any suggestions as how to overcome the problems of obtaining representative samples from below the water table without disturbing the system.

Tahal investigations

Some time was spent with Dr. Mercado of the Water Quality Unit within Tahal. He has looked at the long term build up of dangerous contaminants such as nitrate, chloride and heavy metals in groundwater and has attempted to model the build up to predict regional trends for planning purposes. A paper of his, dealing with the nitrate and chloride problem was recently published in the

Journal of Hydrology (see Bibliography). A brief resume of some of his work is as follows.

Agriculture and reuse of treated sewage effluent both result in longterm build up of contaminants in groundwater. Such contaminants include chloride, nitrate and heavy metals. Nitrate results from fertilizers, animal wastes, etc. and eventually finds its way to the water table via recharge and return irrigation flow. Nitrate balances show something like at 17% accession to the water table per annum eventually resulting in undesirable levels being reached in areas where groundwater is used for human consumption. Protective measures in the form of reduced fertilizer application and proper control of wastes will become necessary. The problem here is that the protective measures may come too late due to naturally delayed aquifer responses i.e. the unsaturated zone may already seriously be contaminated. Groundwater exchange, i.e. importingdrinking quality water and exporting agricultural quality water, could be a solution.

Chloride builds up in irrigation areas and infinitum, being removed neither at the surface or in the unsaturated zone. Chloride balances in some areas show build up of 300 mg/l in 35 years, serious when thinking ahead 50 or more years. Unfortunately little can be done to alleviate the problem but to import and export as above,providing there is an abundant freshwater reservoir available. Again expense can be the limiting factor.

Heavy metals are particularly associated with sewage and are not eliminated in the treated effluent expected to be used in agriculture when the Dan Scheme is fully operational. They also build up in areas where pesticides, weedicides etc. are used. Little is known about their behaviour. Many may be absorbed by soil constituents becoming partially retained in the unsaturated zone for long periods say the order of hundreds of years or so. However,soil components (ionic and organic) may form complex as with certain heavy metals (i.e. Cd++ reacting with Cl^- or organic complexes giving $CdCl_3^-$ or organometallic compounds) reducing transit times. Mercado's approach to the problem (bearing in mind Israel's limited water resources) has been to model a simplified systemof pollutant transport based on previous water and salt balance studies, obtaining Cl^-, NO_3^-, heavy metal etc. balances within a network of cells in the coastal (Pleistocene) aquifer and predicting where serious build up will occur. Rather than concentrating on one particular species, studying its movement through the unsaturated zone he has assumed uninhibited flow to the aquifer (as with Cl^-). Average values are used for all parameters to obtain predicted build ups (all processes are assumed to behave linearly). Then ranges of parameters may be used to see how sensitive the pattern is to each. Some of the decision variables which will affect the model are as follows.

(i) what to choose as a target year i.e. 2000, 2020 etc.

(ii) how much recycling of groundwater can be allowed (i.e. reuse of treated sewerage effluent) if this is a major source of heavy metal concentration.

(iii) should further controls be placed on the effluent concentration i.e. additional treatment costs which may affect the economics of agriculture, vital to the country's survival.

The whole concept of the project has been to produce a useable model for planning and management purposes. 1, 2, 3, above are needed to proceed further.

Instruments

Various instruments e.g. water level recorders, probes, current meters use in Israel are made by a division of Taman, the Israeli aircraft factory. A copy of their brochure is in Divisional Files. A little more detail on some of them follows:

(i) Water level recorders - the upright rotating drum type are preferred.

(ii) Water level probes - these use the casing or pump column as the second electrode rather than a second wire - okay if wells are cased to water level. This has the advantage of reducing the bulkiness. The probe is attached to a strong, plastic coated graduated and non stretching wire. The bottom electrode is weighted with small brass weights attached so when jamming occurs, they and the electrode drop off into the well, enabling retrieval of the probe wire and attachment of another electrode.

(iii) Specific depth samplers - these work on exactly the same principles as those used within the Department.

(iv) Current meters - these are manufactured and tested within Israel - giving about accuracy to 5%. They use slightly larger propellors.

(v) Salinity and temperature logger - this unit can measure simultaneously temperature in a range 0-50^{o}C and salinity from fresh to sea water over a depth of 400 m. It is battery operated, portable, compact and usable in wells as small as 30 mm diameter. Total weight is 15 kg (two items). This device could be extremely useful in field operations. Comparison is required between it and that which the Department already has.

In summary, there is little difference between their sampling equipment and ours, the only feature being the shiny metallic finish (chrome, brass etc.) on items 2 and 3 making them considerably more expensive than our own.

Water rights, quotas

In Israel, the rights to water lie with the individual but the Government controls the allocation through the Water Commission (see earlier). Allocations are based on different principles depending on usage. With agriculture, it is based on crop usage (as adopted at Padthaway). When the quantity required to irrigate a crop is allocated it cannot be altered - irrespective of whether the farmer wishes to change to a crop type using more water. Control is achieved by using up to date aerial photography and ground checking. If an individual is obviously using over his quota he is advised and has the right of appeal through a public committee. If the appeal is upheld i.e. he can justify the additional usage either through economics, national security etc. only then will his allocation be altered.

Within industry, a similar means of alloting quotas is used. So much water is allowed to produce say each tonne of paper or wash each tonne of sand. A similar right of appeal exists.

With the urban community, water is allocated to the municipal authorities who in turn distribute it to the individual.

Appeals, if not upheld by the public committee, may be taken to court presided by a professional judge who has access to expert witnesses (e.g. engineers, hydrogeologists). Such cases are rare and usually unsuccessful.

Considerable investigation into reduction of per capita usage has been undertaken in Israel. Water pricing policies have been implemented to dissuade farmers, industry and urban populations from using above quota amounts. Excess water rates are proportionately much higher than here. In addition in agriculture, accent is on more efficient irrigation techniques with much research into sprinkler and drip methods. Flood irrigation is a rare occurrence. In the urban community, people are not encouraged to maintain large gardens, lawns etc. in an attempt to reduce consumption.

Water Usage

(brackish, effluent, harvesting)

Various sites were visited throughout Israel where experimental usage of brackish water and partially treated effluent, desalination, water harvesting were being tried in an effort to utilize water resources previously considered unusable.

Brackish water (>3 000 mg/1) has and is being used to irrigate peanuts, tomatoes, onions and salt bush (as a dairy fodder) and in fish farming (carp). Salt appears to be no problem as there is good drainage to the nearby ephemeral streams and deep water table. Primarily treated effluent (aerated) is being successfully used for alfalfa (lucerne) production. Small scale desalination plants - of the electrodialysis and reverse osmosis type, are being used to produce supplies for kubbutzim and experimental farms in the drier desert areas. The practice of "water harvesting" is gaining popularity in the drier areas. Here, rows of 10 x 10 m plots are constructed so that all runoff into each plot is channelled to one corner where a fruit tree is planted (e.g. pistachio, olive, almond, peach). The runoff during winter (rainfall 150-200 mm) is enough to keep the tree alive during the following summer which is totally dry.

Other efforts have been to cut down gross consumption in agriculture by using more sophisticated forms of irrigation. Trickle irrigation is the most popular here. Brackish water is used with good results and fertilizers can be added in liquid forms in a much more efficient way than before. There are at least two agencies carrying out research into such problems, the Negev Institute for Arid Zone Research at Beer Sheva and the Volcani Centre near Tel Aviv. Some of the projects include studies of plant physiology in the arid environment, dry land farming in low rainfall areas, nitrate pollution through agriculture, soil physics and soil salinity. In addition both centres offer field extension services to farmers.

~~Exploration~~ Evaporation prevention

Engineers within Tahal have for some time been studying the problem of preventing evaporation from water surfaces in an effort to thereby increase available water resources. The principle of the process is to cover the water surface with a mono molecular layer forming an evaporation barrier. This is achieved by spraying a long chain alcohol-water emulsion on to the surface using a system of sprinklers.

Problems which have arisen include the following:-

(i) Measurement of the effectiveness of the cover i.e. it is very difficult to precisely measure evaporation before and after treatment.

(ii) Wind is a nuisance, speeds greater than 20-25 km/hr breaking up the cover and reducing its effect drastically.

(iii) The mono-molecular layer itself causes build up of heat storage within the water body leading to increased evaporation on break up of the film.

(iv) The methods so far used are labour intensive.

(v) The cost of chemicals used has risen enormously.

The overall conclusion on the experiments conducted so far is that the process is uneconomical for large water bodies but something like a 12% reduction in evaporation may be achieved with smaller bodies i.e. farm dams. The next step proposed by Tahal engineers is to try materials that reflect radiation rather than to reduce evaporation using mono-molecular layers.

Training in Hydrogeology

Under graduate training is carried out at the Hebrew University as part of a normal science degree. There is an excellent post graduate course run by Professor Mandel at this university within the Centre for Groundwater Research. J. Forth, of the Water Resources Branch, Engineering and Water Supply Department has attended and highly recommends it. The course is run yearly between December and May and is titled "Exploration and Development of Groundwater Resources". All aspects of hydrogeology are covered. The course involves lectures, tutorials, written examinations and preparation of a short paper. At the conclusion students are given a diploma, recognised at most universities as equivalent to 35 credit points toward an M.Sc. degree. It is envisaged that shortly a full time M.Sc. course will be available.

Several students at the Research Centre are doing doctorate degrees on various aspects of groundwater.

FRANCE

13/9/75 to 30/9/75

All time in France was spent with personnel of the Bureau Recherche Geologie et Mineralogie (hereafter B.R.G.M.) at various offices in Orleans (head office - 2 days), Marseilles (2 days) and Strasbourg (1 day). B.R.G.M. is a semi government organization carrying out consulting work for the French Government and for various countries. In Orleans we visited their Hydrogeology group which together with the Geotechnics group have a common data bank and a statistics, hydrometric and computing service. The two other offices are part of their group of regional offices, Strasbourg being a little different as it includes the Geological Survey of the Alsace region and has a large group working with hybrid (analogue & digital) models. The regional offices in general tend to deal with local problems.

Legislation and control of water resources in France

Surface and ground water is controlled by numerous authorities at national, regional and local levels. Controls on groundwater include:

Well Permits

Permits are required for all wells greater than 10 m deep by the Ministry of Health for quality reasons. Applications are submitted for approval by an appointed geologist. He may or may not make some comment regarding supply. On completion, well details (not including a log) are submitted to B.R.G.M. by postcard.

Water quantity

There are no controls on phreatic wells as these tap rivers water which is everywhere abundant. Controls on wells which penetrate confined aquifers have existed in some areas as far back as 1935, such as in the Paris Basin.

Water quality - pollution

There are laws regarding waste disposal via wells. These are difficult and costly to enforce and succeed in catching only the large polluters.

For wells they have a set of perimeter rules to limit contamination:

(i) 0 - 10 m - inner perimeter - no buildings are allowed, area must be enclosed for protection.

(ii) 10 - 100 m, no garbage disposal, fuel storage or various other practices allowed.

(iii) 100 - 1 000 m - as above, depending on aquifer conditions.

These criteria could be quite useful if modified and adopted for South Australia - especially septic tanks and domestic water supplies.

Data bank, storage B.R.G.M.

Only within the last few years have B.R.M.G. been filing well data on computer tapes etc. A large 18 000 word Thesaurus has been used for well logs (their data storage system is not just water wells - it includes geochemistry, petroleum and mineral exploration data)

Examples of some of their files include:

(i) piezometric levels

(ii) water chemistry (divided into various ions, heavy metals and other pollutants)

(iii) well details

(iv) hydrological data i.e. stages, flows.

Forms of data retrieval are for:

(i) (a) water level vs. time (plots or print outs)

(b) all readings for one year, times measurements taken

for

(ii) (a) salinity vs. time plots or print outs

(b) ion concentrations vs. time plots on Piper trilinear diagrams

(c) contours.

Hydrogeological projects

Some of B.R.G.M.'s hydrogeological work which we discussed included:

at Orleans

Modelling

Studies carried out include research into the following:

(i) One Phase

(a) Simplest cases - steady state assumed, square cells used in model. Numerical techniques not required.

(b) Transient phase considered - larger computing facilities needed

(c) non linear problems

(d) multilayer cases

(e) 3D problems where Dupuit assumptions do not hold
Often here the upper boundary limits are unknown.

(f) Progression to varying shaped cells.

(g) Use of finite difference and finite element techniques in more complex situations.

(ii) Two Phase

(a) Pollution i.e. tracing pollutants from a river through aquifers to well fields using so called "Sharp front model" and later "dispersion model". Salt-water or tracer injection used here to verify modelling.

(b) Saltwater intrusion either via rainfall to aquifer from by product of potash mining (see later) or within phreatic aquifers at coast. Here dispersion was not taken into account and an average "front" position assumed. Two situations with the coastal interface problem were considered, the first where no flow occurred at the boundary (i.e. pressure fixed and a function of vertical position of water table), the second where transient conditions exist at the interface.

(c) Effects of recharging heated cooling water to aquifers.

(d) Stochastic treatment of data i.e. rainfall.

(iii) Pollution

Detailed investigations of the nitrate problem in groundwater. Studies using isotopes showed concentrations up to 200 mg/l in groundwater to result from over fertilization of agricultural land. A partial solution has been achieved as rising costs have forced farmers to lower the application rate.

at Marseilles

(i) The Fos area near the Rhone Delta - an area of potentially large groundwater resources at shallow depth. A mathematical model was developed to assess total resources and as a means of planning future development - siting industry and urban expansion to reduce pollution risks and to gauge effects of future groundwater withdrawals on the aquifer.

(ii) Investigations of localized water pollution problems at Miramas and Cannes (sewage contamination of groundwater).

(iii) Investigation of problems caused to farmers in the Le Var River valley near Nice by wet dredging gravel mining.

(iv) Some experimental work in trapping seaward groundwater flow in a karstic area near Cassis - fairly expensive research but may prove practicable in areas such as Greece and Turkey where water shortages are expected over the next few decades. Groundwater enters coast via a large conduit which has been partially dammed, reducing sea water intrusion and lowering salinity to 3 000 mg/l. The second stage of the project is to completely seal this conduit by constructing spill ways. One problem expected is flow exit elsewhere.

Strasbourg

(i) Pollution in the Rhine Valley - Mulhouse area. Here sodium chloride, a byproduct of evaporite mining, enters the groundwater system via infiltrating surface waters. A distinct plume has developed with a northerly trend to the Rhine. There are also various industries, towns etc. which discharge their wastes either directly or indirectly into the Rhine Valley. B.R.G.M. people have developed a mathematical model of the system using piezometric data back to 1950 and estimating storage coefficient and transmissivity for the most part. Transmissivity distribution for example was obtained through correlation with resistivity data. Here they use analogue models coupled with a digital computer. Although the analogue models are little used elsewhere in the world now - the B.R.G.M. people maintain they can achieve far more accuracy than the straight mathematical models - even though the analogue model takes considerable time to construct and is therefore more expensive. Procedure is as follows:

(a) Produce very simple mathematical model of system to obtain rough idea of capacitor, resistor values etc. required.

(b) Build model with data available - run for steady and unsteady state. Generators are used for the various signals to the model i.e. pumping, infiltration, boundaries etc.

(c) Couple with computer.

(d) For more detailed information on specific areas within the model, sections may be removed and enlarged.

So far, their models have been used for pollution studies and optimum well spacing (e.g. in well fields) rather than complete management of an aquifer.

Field Activities

Drilling

Subcontractors are used for all their work. Drilling methods were not discussed.

Sampling

Water samples are obtained by standard methods - from normal to large diameter boreholes. Hach field kits are sometimes used for dissolved O_2, CO_2 etc. measurements (these have been found most reliable). Their laboratory chemists do all analyses. Analytical laboratories are very similar to A.M.D.E.L. covering a very wide range of work and not just routine water analysis.

Use of tracers

We were unable to get to Montpellier where some of this work has been done. Marseille people have only just started using tracers in their investigations. Types of tracers used are uranine, sodium, iodate, lithium chlorate, rhodamine B and sulphorhodamine. Detection is by means of a fluorimeter.

Geophysics in groundwater investigations

Logs

Various run, similar to those used in our work.

Resistivity surveys

These are used to obtain:

(i) depth to basement contours in areas where alluvial or sedimentary sequences overlie bedrock (either metamorphic or igneous - generally denser sediments). This technique has been fairly successful in various locations throughout the world. There appears to be no apparent difference between their operations and those of our Geophysics Division.

(ii) A detailed look at near surface resistivities to predict potential freshest groundwater occurrences. The technique is also used for delineation of least resistive zones which might be freshwater saturated sands.

(iii) Interface work - estimating depth of fresh water zone overlying salt water, its salinity and possible usage i.e. whether suitable for domestic or stock purposes ur unusable.

(iv) Correlating resistivity with transmissivity. B.R.G.M. staff have successfully used resistivity results together with point transmissivity values to give reasonable transmissivity distribution plans in areas where modelling is attempted. Field results are combined with groundwater resistivities to give formation resistivities which when plotted against known transmissivities, give an empirical relationship suitable for the area concerned. In this way - large number of resistivity soundings are available can yield a quite accurate distribution.

Publications

B.R.G.M. has issued a large number of coloured hydrogeological maps. These are very useful but are expensive and must be updated from time to time. The trend is now for black and white. Legends and maps are drawn to UNESCO standards (based on their own experience).

Contact was made with their librarians who in future will send annual lists of publications to our library plus any specific items on groundwater. French translation will be required.

Conclusion

France does not appear to have any major groundwater supply problems and only limited quality problems. I could not find many similarities between their groundwater situations and ours. As far as is known - there is no strict management of the resource. Artificial recharge is of minor importance if any. Personal contact is maintained between P. Manoel and Pierre Ungemach and receipt of B.R.G.M.'s annual catalogue of publications should ensure up to date knowledge of their advances in modelling techniques.

HOLLAND

22/9/75 - 23/9/75

The two days in Holland were spent with Professor Van Dam at Delft University, the Groundwater Survey Division of T.H.O. (akin to C.S.I.R.O.) and the Rhineland Water Board. Water in Holland is derived predominantly from the Rhine, groundwater resources being fairly limited. Unfortunately, water supply involves many different government and private organizations though all are under some control. Much of Holland is near or below sea level. Rhine water has been used to flush out connate salts in reclaimed areas providing fresh supplies for agriculture. Canals are used for both drainage and water supply. The principles behind water resource management in Holland involve maintenance of groundwater levels at a fixed depth just below the surface so it is accessible to root systems of most crop types. This depth varies from 50 to 150 cm and thus changes in water level even of 20 cm or so may have drastic effects on agriculture.

T.H.O. - Groundwater Survey Division

More practical points arising from discussions with staff of the above organisation are as follows:

Observation Wells

A national grid covers the whole country. Half of these are read fortnightly, the rest at varying intervals up to about 4 times a year. Many levels are measured by unpaid observers who are supplied with a booklet of post paid postcards on which are spaces for depth to water, date and time of measurement. All data received by the survey goes on to computer file and can be retrieved in the form of hydrograph plots, straight SWL vs time tables or contours.

At the time of visiting T.H.O. no rationalization of the network had been undertaken but was planned for the near future when funds would become available. Water quality data had not yet come on to computer storage.

Geophysics

(i) Logging

Since 1967, all new wells in Holland have been drilled using rotary techniques enabling electric logging of each to be carried out. Standard practice in open holes is to run short and long normal resistivity, gamma ray and caliper logs. On completion, temperature, differential temperature, conductivity and again gamma ray logs are run. In addition, a flow meter is used. The two temperature logs are used to determine areas of groundwater recharge. Careful plotting of isotherms vs depth below ground level along sections shows variations which can indicate areas of infiltration or discharge. The principle relies on there being sufficient temperature difference between infiltration moisture and that of the groundwater body.

(ii) Resistivity

Common resistivity techniques have been used to delineate the fresh water - salt water interface which occurs everywhere beneath the country.

Modelling

Some groundwater modelling is being carried out by T.H.O. who are hoping to use the technique for management purposes - controlling water levels so as to maintain them at optimal depths for agricultural purposes. One problem as mentioned above is the large number of organization involved in water resources in Holland. Fourteen are involved in the modelling work.

Interesting aspects of their work are the use of finite difference techniques utilizing a grid of polygons and finite element techniques utilizing a grid of squares - opposite to the normal. Transmissivity distribution for the model has been calculated by comparing known hydraulic conductivity (from normal aquifer or well tests) with surface area of the aquifer material (i.e. related to size distribution) and obtaining a relationship which can be extrapolated to other areas where particle size analyses are known. This procedure must be used with care and not used for extrapolation too far from physically determined data. It is rather like the constant relationship that is found between the formation factor (Ø) and permeability for reservoir rocks in local basins.

Artificial Recharge

An artificial recharge site (privately run and owned) was visited near the coast at Leiden. Rhine water is used for recharge via wells and infiltration ponds in portion of a conservation park in a sand dune area. Originally problems of precipitation in the wells arose through high entrance velocities but the scheme has now been modified to overcome this. Silting in the filtration ponds is also a problem and to rectify the situation a tractor with a special device for cleaning the surface layers used. The recharge water is recovered after 6 weeks, filtered with activated charcoal to remove iron and oxygenated before being introduced into the water supply system. The input is about 40 - 50 million cubic metres per annum, output being just less.

UNITED STATES

24/9/75 to 29/10/75

Battelle North West Laboratories - Richland, Washington

Introduction

Battelle is a large consulting and research organization working in many fields - including surface and groundwater hydrology. Their main consulting job at Richland is an on-going contract with the U.S. Atomic Energy Commission and involves study of the problems of radioactive waste disposal (the Hanford Project). Battelle scientists and engineers have developed a set of mathematical models describing flow in the saturated and partially saturated zones and contaminant transport through these zones and it was for this reason we visited the Richland Labs. We met with people from the Water and Land Resources Department of Battelle Northwest.

Models developed by Battelle

These are described simply by function, input and output.

Variable thickness transient flow model (VTT) - see Cole and Reisenauer, 1974

Function

Simulation of saturated flow

Input

(i) Transmissivity distribution. Hydraulic conductivity considered variable in x and y direction but constant in z direction.

(ii) Initial conditions

(iii) Boundary conditions (includes location and quantity of discharge and recharge).

Output

(i) Potential map

(ii) Groundwater velocities

(iii) Flow paths

(iv) Flow rates

(v) Travel times

Partially saturated transient flow model (PST) - see Reisenauer, Cearlock and Bryan, 1974.

Function

Simulation of saturated and partially saturated flow in the vertical profile.

Input

(i) Saturation versus capilliary pressure curves

(ii) Permeability versus " " " (done in lab.)

(iii) Boundary conditions

(a) flow rates and volumes

(b) elevations

(c) depth of each soil layer

Output

(i) Potential map

(ii) Moisture contents

(iii) Flow velocity

(iv) Flow vectors

Micro - macrotransport model (MMT) - see Ahlstrom, 1975

Function

Simulation of contamination transport in saturated and partially saturated flow systems (approx. 3D systems).

Input

(i) Velocities (from VTT or PST models)

(ii) Initial concentrations

(iii) Boundary conditions

(iv) Discharge descriptions

(v) Ion exchange, chemical reactions, radioactive decay.

Output

Time dependent concentration distributions.

Some research projects

Chemistry of salt, pollutant movement in ground and surface water - see Rouston and Serne, 1972.

Two important points brought:

(i) Heavy metals, radio nuclides and other contaminants may be tightly held in the soil but microorganisms in that same soil, produce acids which may form soluble chelate complexes with these pollutants enabling downward percolation to and contamination of the water table or their uptake by plants and then animals and/or humans.

(ii) Heavy metals tend to precipitate very quickly in rivers and be absorbed on to sediment particles, usually the clay fraction. It is therefore very important that sediment size analysis be taken into account when dealing this problem.

<u>Eutrophication of lakes and rivers</u>

Battelle people have a wide range of experience in this subject. The Engineering and Water Supply Department have already used Battelle in this field.

<u>Some Battelle consulting projects</u>

<u>Hanford project</u>

This, as mentioned above, is the main consulting job of the Water and Land Resources Department at Richland. Work to date includes:

(i) drilling and maintaining a network of observation bores

(ii) monitoring water levels in these bores. Groundwater is recharged regularly with heated water from the nuclear reactions on the site.

(iii) Sampling the groundwater for a variety of contaminants - mainly radio nuclides and nitrates - waste products of the nuclear fuel producing processes.

(iv) determination of aquifer parameters

(v) developing mathematical solutions to groundwater flow problems in order to model the aquifer system beneath the Hanford site and be able to predict long term pollution trends and effects of failures in the radioactive waste disposal system (see earlier - VTT, PST and MMT model).

(vii) some lysimetry to determine recharge - this proved to be zero (water table is 70 - 90 m below ground level and rainfall about 200 mm).

Part of the work is reported in Cearlock (1972). The development of a model of the Handford groundwater basin, a heterogeneous aquifer, necessitated quite accurate knowledge of transmissivity distribution - more than that known from pumping tests. To overcome this problem, Cearlock (1975) developed a transmissivity iterative routine which is a direct method of solving the inverse problem using numerical simulation techniques to link the field measured aquifer property data with the measured hydraulic potential data in order to define a hydraulic conductivity distribution. Incorporation of additional information from the hydraulic potential surface configuration produces a much more accurate hydraulic conductivity distribution than would be possible from measured conductivities and qualitative geological information alone. The added advantage of this technique is that it can be used in conjunction with a hydraulic potential contour plan to determine where aquifer tests need be carried out to give maximum information for minimum cost.

Ahtanum - Moxee Sub-basins, Yakima County, Washington

This area is described in Cearlock et al. (1975). A mathematical model was developed for the aquifer-river system in order to predict long term effects of ground water usage on the basin and for management purposes (see Figs. 8 & 9 for cell shapes, aquifer boundaries and assumed transmissivity distribution).

Clark County, Washington - Groundwater Resources

Here, a mathematical model of an aquifer system beneath Clark County is being prepared for utilization in planning and development by the County authorities. They hope to be able to use the model to predict effects of new well fields, sewage treatment plants etc. on the aquifer and to control well site selection to avoid interference. At the moment this work is in the basic data preparation stage. This has included -

(i) location of all wells in the area from various information sources.

(ii) location of all surface geological and topographical information.

(iii) evaluation of available stream gauging information selection of grid for model, delineation of model boundaries

(iv) determination of aquifer parameters, soil characteristics and recharge for each cell etc. It is interesting to note here the detailed soil maps which were available. These not only gave details on soil types and thicknesses within the area but also data on infiltration rates, water capacity, permeability. For each cell, the following were obtained:

(a) top and bottom of aquifer and thickness

(b) rainfall - may have to be adjusted depending on elevation, frequency and location of measurements

(c) diversion statistics i.e. irrigation from outside water sources

(d) pumping records

(e) some water level history - initial state and pre-and post-irrigation season levels.

(f) evapotranspiration - determined on monthly basis as significant data is available. The methods used here to compute the actual evapotranspiration is similar to that used for Padthaway.

(g) transmissivity and storage. The iterative routine may be useful here in giving distribution.

To date this has all been done by the hydrogeologist (note similarity with Israeli system). Data have been processed, contour maps drawn on computer for later calibration. The modelling will be handled by people with mathematical and computing background (engineers, physicists in this case). This appears to be the most common method of approach to such a problem in Battelle.

Hood Canal

This is a project in which the effects on an aquifer of constructing a dry dock on the edge of the Hood Canal near Seattle are being examined. Anticipated problems are those of sea water intrusion and declining groundwater levels when the dry dock is dewatered. Recently an attempt was made to simulate the system using a minimum of data and a 15 day pump test for calibration. We were fortunate in being able to see some of the calibration efforts - the trial and error method of selecting aquifer parameters and infiltration rates, simulating the pump test on the model and comparing the results with observed values.

Comparisons were made by direct (in line) print out from a Calcomp plotter (see Fig. 10). After reasonable calibration is achieved, the Battelle Staff working on the project (an engineer and physicist) hoped to refine their model further by examining soils, topography, geology etc. of the modelled area. It was interesting to see them go so far without reference to such information.

During this project both people developed computer programmes to analyse pump test data - the semi-log plot for confined aquifers and the leaky aquifer plot. Copies of both programmes were made available to us (with P. Manoel).

Practical operations

Drilling

Nearly all drilling is carried out by cable tool rigs on the Hanford Project. They have used rotary Mayhew 1000 and Failing 1500 rigs but these are useless in fluvio-glacial gravels. Where one or more aquifers is encountered separate wells to each are drilled or the technique of cementing thin piezometers each open to a different aquifer in a single large diameter well is used.

Completion

Two methods are used - either screens or perforated casing. They have an on going problem with rehabilitation of 20-30 year old wells. Many of these have only rough drillers logs and require development through surging as they were never initially developed.

Logging

New wells and rehabilitated wells are logged with a combination of the following:

(i) gamma ray

(ii) neutron

(iii) caliper - uncased lower portions of well (often in basalt)

(iv) temperature and differential temperature

(v) flow meter

The unit used is a Widco (Gearhard Owen) 0-06-3600. No electric logs are run as all bores are cased.

Sampling

Sampling techniques include grab sampling, air lift or if well diameters are large enough, a submersible pump driven by a truck mounted generator is used. Samples generally reach the lab for analysis within 2-3 hours.

Optimization of well network

This has not been carried out as yet,but is being considered.

TV Camera

Battelle North West have a Sony Video tape unit and down hole camera which is used to look at old well casing, screens and aquifer in uncased holes. A video tape enables replay back in the laboratory.

Data processing

This has tended to be rather specialized for their own Handord Project data. P. Manoel has more details.

Conclusions

The visit to Battelle Northwest Laboratories was worthwhile from a geologist's point of view in that some insight into detailed aquifer modelling and the use of computing facilities was gained. Also of interest was the role of the hydrogeologist in their organization which I have already mentioned. The visit was very useful in that computing programmes for pump test analysis were obtained. These, with modification could prove useful in our own work,saving considerable time (pump test analysis). A step drawdown analysis programme could be written based on those obtained during the visit.

Their practical methods differ very little to ours. No new information was gained here.

One disadvantage with Battelle Northwest is their lack of experience with our sort of problems i.e. the saline water table overlying a fresh confined aquifer situation. Their main working area - Northwestern United States, has plenty of surface water and groundwater and very few problems with salinity. Their models tend to be used more for prevention of interference, analysing local decline of groundwater levels, siting of industry, sewage plants etc. rather than predicting long term salinity changes within a groundwater system.

Montgomery Engineers - Pasadena California (6-8/10/75)

The above company is a consulting organization specializing in some fields of water resources. Much of their work has been associated with water supply and treatment systems in Southern California. Los Angeles, an urban sprawl up to 150 km long and 30 km wide,is a dry area with rainfall less than 250 mm and receives its water supply from a variety of sources which include Northern California and the Colorado River via canals and aqueducts, groundwater extraction beneath the area and local runoff. Groundwater may be naturally occurring, recharged storm water, desalinated sea water or treated sewage effluent. Several sites were inspected where such operations are taking place.

Rio Hondo spreading grounds

The Rio Hondo River flows through the central portions of the Los Angeles area. Beneath it are up to 300 m of coarse alluvial and fluvial sediments (active movement of San Andreas Fault system).

Reservoirs have been constructed upstream in the mountain areas and during high flow periods water is released down the river to an area of spreading grounds to recharge the aquifer where groundwater supplies are extracted for urban and industrial consumption. The spreading grounds occupy flood out areas either ~~wise~~ side of the main concrete lined channel and consist simply of shallow excavated pits. The grounds are used really for a form of flood mitigation with contact maintained between reservoir spillway and spreading ground operators. In wet years, increases in head of up to 9 m have been observed beneath the spreading ground. Clogging is overcome by removing silt (usually <300 mg/l in floodwater) by scraper and adding a thin cover of sand from the river bed.

This technique of artificial recharge is so successful that little runoff reaches the sea. In dry years imported Northern California or Colorado River water is recharged.

A similar system is in use in the San Gabriel River valley where most recharge water is imported and is only local when flood mitigation is required. Artificial sand banks and levees are built during dry periods to slow down flow rates and increase recharge rates when storm water is available.

Orange County Water District

Orange County (within the Los Angeles district) has an interesting supply system. Sources include demineralized waste water, naturally occurring and artifically recharged groundwater, imported Colorado River water and desalinated sea water. Artificial recharge is carried out along the Santa Ana River in a similar way to that described above although importantly, they have created recreational lakes out of the recharge ponds. Recharge via wells near the coast (only just implemented) is maintained to prevent sea water intrusion resulting from large scale groundwater withdrawal. Problems have arisen over costs - especially the desalination but otherwise the rest of the operation is economic. Nitrates in the Santa Ana River water resulting from agricultural practices may prove a problem in future.

Pomona City water supply

Water supply is derived from a number of sources - local storm runoff, blended imported water from Northern California and groundwater from the Chino Basin beneath the city. The groundwater basin is small and in an overdraft state producing subsidence problems including telescoping of casing, excessive pumping costs and induction of nitrate into the area from agricultural areas to the northeast. Plans to rectify the situation include the purchase of additional imported water and utilization of stormwater for basin recharge and also to purchase treated waste water from the Los Angeles County Sanitation District and provide it to agriculture, industry and for replenishment and recreation (i.e. artificial lakes).

Chino Basin Tertiary Treatment Plant

This plant receives about 70 000 m^3 of water a day from an adjacent trickle filter plant which removes about 80% of solids from raw sewerage.The water then undergoes alum treatment (flocculating effect), is filtered through 50 cm of anthracite and 25 cm of sand and finally chlorinated before being sent down stream to percolation basins where it is eventually recovered from the groundwater reservoir after about 6 months. Salinity is about 500 mg/l and up to 40 mg/l consists of nitrogen in the form of nitrate and ammonia - desirable in that anaerobic activity is prevented. Mixing in the aquifer and on pumpage reduces this level to one safe for normal usage.

Conclusion

Although many different organizations, both government (including city county, state and federal) and private, all have parts to play in water supply in the Los Angeles area, schemes appear economic and work. Practical results of mixing waters of different origin via artificial recharge are everywhere evident.

El Centro Field Station - Imperial Valley

10/10/75

The Imperial Valley is in southernmost California adjoining the Mexican-United States Border. Here large scale agriculture is practised - worth some $500 million annually. The rainfall is less than 75 mm and all crop water requirements are supplied by irrigation. Surface water originates from the Colorado River some 100 km to the east - being brought into the area by the All American Canal. Groundwater salinity is around 800 - 900 mg/l and unfortunately on the increase. Similar problems which River Murray irrigators face with drainage water (4 000 mg/l) are encountered. Fortunately they have a large low level saline lake into which irrigation drainage water can be disposed (by means of plastic tile drains - laid by machine at very fast rates). However, the level of this lake (known as the Salton Sea) is rising at a rate of about $^1/3$ the irrigation application rate and may create the need for major earthworks to control inundation in the future. In addition salinity (40 000 mg/l) is also rising effecting recreational uses of the area (salt water fish gradually dying out).

United States Department of Agriculture Field Station, Brawley

10/10/75

Brawley is also in the Imperial Valley. At the field station, most research is associated with evapotranspiration. A weighing type lysimeter is maintained at the site and results are used to plan irrigation schedules for most crops over the whole valley as conditions there are so homogeneous. Their schedules have been so reliable that they can be adhered to year after year. Some other research on drainage and plant breeding is carried out.

University of Arizona, Tuscon

Water Resources Research Centre

13/10/75

This faculty is headed by Professor Stan Davis (of Davis and DeWiest) and was visited to learn something of the courses available in Hydrology. Post graduate courses are virtually equivalent to an M.Sc. degree. Almost all aspects of hydrology can be studied - from practical exploration, management, legal aspects, water usage etc. Pre-requisites include a normal B.Sc. or B.E. degree, the science student possibly needing to take some undergraduate mathematical subjects. The syllabus is in Divisional files if further information is required.

Research at Tuscon includes:

(i) work on artificial recharge using sewage effluent. In some instances wells are used with multiple inlets to allow recharge to different horizons. In others, stream beds (normally dry) are utilized (see Wilson, 1970, 1971, 19??).

(ii) work on seepages through the unsaturated zone in arid areas where water tables are greater than 15 m below ground level. Some success has been achieved with temperature measurements through the unsaturated profile enabling tracing of infiltration pulses (see Bredehoft and Papadopoulos - Water Resources Research 1965, vol. 1 (2).).

(iii) legal aspects of water usage, the problem of prior appropriation in areas of overdraft or in areas where water rights go with Federal land, yet the water resource may be required for State development.

(iv) hydrochemical work using fluorocarbons to estimate recharge rates (suitable only for ages less than 30 years). In discussions with Professor Davis on practical aspects of sampling and analysis he recommended Hach kits but for reconnaissance work only. He has found fluid quantity precision poor. Silica, bicarbonate, calcium and total hardness kits are satisfactory but sulphate results are not so good. The photometric technique for iron is satisfactory providing the oxidation state of the iron is known.

(v) some work on semi-arid region hydrology using C^{14}, tritium and deuterium to obtain residence times, sources etc.

(vi) modelling of 3 dimensional transport of tracers (see Simpson, 1975).

Sometime was spent with Mr. Vincent Uhl, discussing water well drilling in India using a rotary percussion (air hammer) rig. Fracture zones were delineated using straight geologic mapping and resistivity to pick up depth of weathering. Most success was obtained in areas off the contact of granite intrusives with Precambrian basement. The resistivity technique was unsuccessful in basalts.

<u>California Department of Water Resources, Fresno</u>

14/10/75 - 15/10/75

A morning was spent with staff of the Fresno office discussing the Kern County aquifer model. Kern County is situated in the San Joaquin Valley between the Sierra Nevadas and the coastal mountain belt. Irrigation using ground and surface water had led to rising groundwater levels in the south and falling levels in the north. Modelling of the aquifer system (two layer) was considered necessary for management purposes. Some notes on selection of various parameters follow:

(i) Boundaries - these were defined either by aquifer limits or where supply and salinity were suitable for irrigation. Where the aquifer extended beyond the model boundary, subsurface inflow or outflow factors were taken into account.

(ii) Cell shape and size - these were generally square, some being polygonal near boundaries. The squares were 5 x 5 km.

(iii) Transmissivity - very little information was available so crude correlations were made between specific yields (from drillers logs) and transmissivity initially. Some re-evaluation was necessary as estimates were sometimes an order in error.

(iv) Leakage - this occurred via wells and gravel packs as well as through confining layers.

(v) Pumpage - here irrigation efficiencies were used rather than extraction rates which were found unreliable.

(vi) Extraction from each aquifer - this was difficult to determine with wells penetrating both. A crude idea was obtained considering percentage open area in each.

Some difficulty was also found in separating water levels for each aquifer.

(vii) Delineation of freshwater zones (four boundaries) - electrical logs used initially - then some drilling of deeper wells.

No attempt was made to achieve steady state calibration as very little early data were available. Instead calibration was based on 15 years of recent data. The modelling was eventually used to locate zones where economic benefits could be achieved by bringing surface water from outside. In addition, it was utilized to predict effects of extraction on consolidation within the aquifer.

Data collection and processing, Fresno

Groundwater, surface water and climatological data are collected in conjunction with the United States Geological Survey, the Water Quality Control Board and the Bureau of Reclamation. Annual measurements take place on 2 000 wells, most six monthly, with the rest at weekly or monthly intervals. A few have permanent recorders. Yearly contour and 5 yearly groundwater level change plans are produced from computer files. Some 150 wells are sampled annually.

Artificial Recharge

All towns in the Valley are supplied from groundwater. Overdrafts are prevented by supplementing with imported surface water from the San Joaquin River system which is allowed to recharge shallow aquifers by over irrigation (flood) and by allowing unlined channels and canals to remain full for long periods.

California Water Resources Board - Sacramento

17/10/75

This organization is a regulatory agency concerned with water quality control. Their work involves research into waste water treatment and water quality monitoring. A congressional Act passed in the early 1970's requires that anybody discharging waste must treat it to a secondary degree. $1.8 billion in grants is available to people or organizations who can document water quality problems. Part of the Board's duties are to distribute grant money for waste water treatment where they see fit.

Waste Water Treatment

Water demands are expected to exceed supply by 5 to 10% in 1990 and by about 20 to 25% in 2020. To make up the short fall various schemes are proposed.

(i) re use - only 10% of effluent is at present treated and re-used. Treated waste water can be used for a variety of schemes all of which minimise health risks to the public. These uses include irrigation of crops which are not eaten raw, fodder production, landscaping, cooling water in industry, groundwater recharge etc. Criteria have been established for each purpose. The Board would like to use treated waste water for recharge to groundwater supplies used for domestic purposes but criteria are difficult to establish. Knowledge of the fate of trace organism and viruses in such processes is scant and a research program on the matter put forward by a panel of consultants formed in early 1975 turned out to be too expensive at a State level. Difficulties have arisen over quality stipulated by the Department of Health who originally required a zero virus count for such water. However, this cannot be measured so other stringent criteria were laid down which required that any waste water be oxidised, coagulated, filtered and disinfected - rather expensive and likely to be uneconomic.

Other problems associated with groundwater recharge are

(a) who pays - who benefits? In most cases all tax payers would contribute but only a few might benefit.

(b) the enormous cost of overseeing the operation - monitoring and data gathering etc.

(ii) increased irrigation efficienty i.e. change techniques to spray or trickle irrigation vs. flooding.

(iii) education of the general public to conserve groundwater i.e. efficiency on the domestic scene.

Water Quality Monitoring and Surveillance

The Board is watchdog on water quality - the guidelines (with State modification) being set by the Federal Environmental Protection Authority. Replanning of the existing monitoring network to suit these guidelines is in progress. The network includes both surface and groundwater stations. Implementation, replanning and optimisation of their networks (both surface and groundwater) are in progress at present to assess ambient and trends in water quality. Man-power is a problem, especially in the groundwater field where only 4 of about 30 basins are at present being monitored. Field data are collected in conjunction with the California Department of Water Resources. Where point pollution sources are located, they are effectively sealed off or stopped by requiring treatment of wastes, replacement or rehabilitation of septic tank systems or wells, installation of evaporation ponds etc. Other controls may be tied up with land use planning e.g. land waste disposal regulations (see California State ...., 1972 and Boulier and Torres, 1969). Where non point resources, usage is examined with regard to restriction to levels within the E.P.A. guidelines.

<u>California Department of Water Resources, Sacramento</u>

20 - 21/10/75

The Department is split into three main divisions:

(i) planning

(ii) design and construction of the California State Water Project

(iii) operation of the project

Most of my time was spent discussing aspects of water well drilling. California in 1975 had few laws regarding water wells. All drilling is carried out by private contractors. This includes work for government departments. Standards for completion have been written. Each groundwater basin is considered separately and may merit additional articles on particular techniques applicable to it. Implementation of standards is on a County basis and not all counties comply. All wells drilled privately are theoretically reportable by the driller (not the landholder) within 30 days of completion. This is difficult to police as government has no advanced knowledge. To remedy the situation tougher penalties and tighter control on driller licences are planned. It is interesting to see that no water or strata samples are required by law. However, most drillers do keep their own records, some very good, which can be retrieved if necessary.

University of California, Davis

Department of Land, Air and Water Resources

Water Science and Engineering Section

22/10/75

The University of Arizona at Tuscon was visited to learn something of courses available in hydrology. A very large and diverse number are available, each if passed count 2 to 5 units towards a Masters Degree (see Graduate Student Manual, Water Science and Engineering, Davis 1975-76). At least 15-18 months of study are desirable depending on the student. One interesting aspect of research carried out at Davis is that of nitrate pollution from animal wastes and fertilizer applications. Denitrification both at the surface and in the unsaturated zone is being investigated. The researcher hopes to be able to determine safe stocking rates and fertilizer application rates.

Other research relates to most aspects of hydrology and includes:

(i) systems analysis, modelling, stochastic treatment of hydrologic data.

(ii) pollutant movement in the unsaturated and saturated zone.

(iii) optimization studies on the California aqueduct system - assessment of the effect of biological growth on roughness coefficients.

(iv) solid waste disposal.

University of California, Berkeley

23/10/75

This campus was visited for the same reasons as Davis. We briefly talked with Professor David Todd on available courses which are slanted towards the Engineering side (include coastal, hydraulic engineering and hydrology). For geologists interested in furthering their knowledge in hydrology, the courses at Davis or Tuscon are preferable.

The afternoon was spent with people involved in remove sensing techniques using ERTS data (more on the processing side) and also visiting the university's Sanitary Engineering and Hydraulics Research Laboratories. Here, work has concentrated on treatment and reuse of sewage effluent, hydraulics of estuaries, wave processes and various other projects a little out of my field at least.

United States Geological Survey Centre, Menlo Park

(south southeast of San Francisco)

24/10/75

At this centre I was fortunate to attend a discussion on a recent mathematical modelling attempt of the Salinas groundwater basin near Monterey in Southern California. Complexities at the seaward end of the basin gave rise to two models - one, a 2 dimensional type to describe or represent water levels and quality changs geophysically and not vertically and a 3 dimensional model at the lower more complex end. A brief discussion on derivation of the model's parameters etc. follows.

(i) Cell size - variable but usually about 1.6 km^2

(ii) Boundaries - aquifer limits on two sides (i.e. no flow) thin saturated sequence on a third and again no flow considered and seaward boundary on the fourth where constant head assumed.

(iii) Hydrologic parameters

(a) Aquifer thickness - the sequence here consists of a mixture of sands and gravels with aquifers at 55, 120, 270 m separated by lenticular clay layers. Details known from well logs.

(b) Transmissivity - very little field data existed so indirect methods were used. A comparison between known hydraulic conductivities and clay/sand ratios in the sequence yielded a type curve which was used over the whole basins area (assuming homogeneous sorting). Clay percentages were then obtained from geophysical logs in areas where no hydraulic conductivity values were available. Where wells only penetrated part of the sequence, the results for this portion were considered representative of the whole.

(c) Storage coefficient - estimated from lithology.

(d) Extraction - energy use as a first approximation. Some problem did arise where flood irrigation was utilized as this technique can be less energy consuming than sprinkler lines. Where wells intersected more than one aquifer, pumpage distribution from each was related to screen dimensions i.e. percentage open area of each to whole.

(e) stream flow - the hydrograph for the only major stream in the basin (Salinas River) was input to the model to cover loss and gain from the aquifer system.

(f) Infiltration (i.e. recharge) - little existed except round the edges of the basin.

(g) Mathematical technique - finite element.

After input of all data and calibration, sensitivity tests run on the 2D model showed it to be relatively insensitive to most basic hydrologic assumptions i.e. boundaries, T, S values etc.

This 2 dimensional model was then used to generate boundary conditions for the eastern limit of the more complex 3 dimensional model which is used to describe both convective (i.e. groundwater flow) and dispersive transport. By now a report on the subject should be available through the United States Geological Survey.

Routine work

The afternoon was spent discussing the types of jobs to which the U.S.G.S. people at the Menlo Park office are called upon to carry out. These include:

(i) Public enquiries i.e. groundwater prospects

(ii) Appraisal of total water resources of areas where information desired (part of the long term polity of the U.S.G.S. to quantify the nation's total water resources). This is often done in conjunction with State or County agencies and can include water balance studies which may be required for management purposes (U.S.G.S. Water Supply Papers).

(iii) Being approached by smaller authorities with limited funds to investigate a particular problem i.e. recharge proposals to prevent undue aquifer depletion or sea water intrusion etc.

(iv) Prepare recommendations on pumpage control, recharge mechanisms or its practicability, well construction etc.

(v) Limited monitoring.

Oregon State Water Resources Department

29/10/75

This organization was visited on the recommendation of California Department of Water Resources personnel as Oregon has more control of well drilling than California. Drillers are licenced through examination on all principles and only after one year's experience on a machine (copies of the exam are with the author). Moral character is also considered before the issue of a licence. All water well drilling contractors (who may or may not be drillers) are bonded. $2 000 must be paid before commencing operations to enforce correct well construction procedures accordingto state standards (see author). If the contractor is registered as a company then $10 000 are required as liquid assets.

CONCLUSIONS AND RECOMMENDATIONS

This study tour has shown that South Australia is not alone in the situation where more than one authority is involved in exploration, development etc. of water resources. Indeed we are fortunate to have only two instead of 5 or 10 as found in Holland and parts of United States. Provided liaison and co-operation incorporating a multidisciplined approach are maintained there is no real reason why the situation should change. In fact, in some ways it is beneficial, each authority being able to objectively evaluate the work of the other.

The Israel portion of the trip was probably the most beneficial. It is clear from that experience that to plan, develop and manage water resources (both surface and sub surface), mathematical description is a must. To obtain answers to questions such as the effects of drought, overdraft, pollution, sea water intrusion and artificial recharge on an aquifer, optimal pumping rates etc. it is obvious that modelling techniques should be used. These can save an enormous amount of time and money as guidelines for future studies.

With this in mind, the following recommendations are put forward:

(i) geologists should become familiar with the basic approach to aquifer modelling. They should understand processes such as setting up the model (using limited or whatever available data), its calibration and predictive qualities, the way in which sensitivity tests are used to locate weak points etc.

(ii) alternative techniques to drilling and aquifer testing be used to obtain approximations to the various aquifer parameters. Estimation based on previous experience is probably the most simple. Otherwise empirical relationships might be found which hold for a particular groundwater basin or area within a basin.

(iii) drilling programmes should be reviewed by a panel (perhaps Tahal style) especially in the light of today's drilling costs to determine just what information the proposer hopes to get from it. Questions such as is the information really necessary or could it be obtained more cheaply by hydrochemistry or from existing wells should be asked.

(iv) a review of water level observation frequency and location be undertaken. If modelling of aquifer systems is to be effective and useful, good hydrographs are a must to enable calibration.

Aquifer behaviour cannot be judged from only one to three readings a year, six or more are preferred. Fewer wells read often in most cases will give more valuable information than many read less frequently.

(v) as a final comment on the trip itself, it is felt more would have been gained had more time been spent attached to a suitable group within an organization such as Tahal or Mekorot and working on a specific project. Too often, days were spent discussing completely unfamiliar subjects with experts and finding at the end of each day, one knew the broad background but not all the detail to fully appreciate perhaps some of the more detailed problems. Apart from that point, the trip was extremely worthwhile, showing especially in Israel, theory put into practice, working and economic.

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AFWilliams

AFW:FdeA
14/10/77

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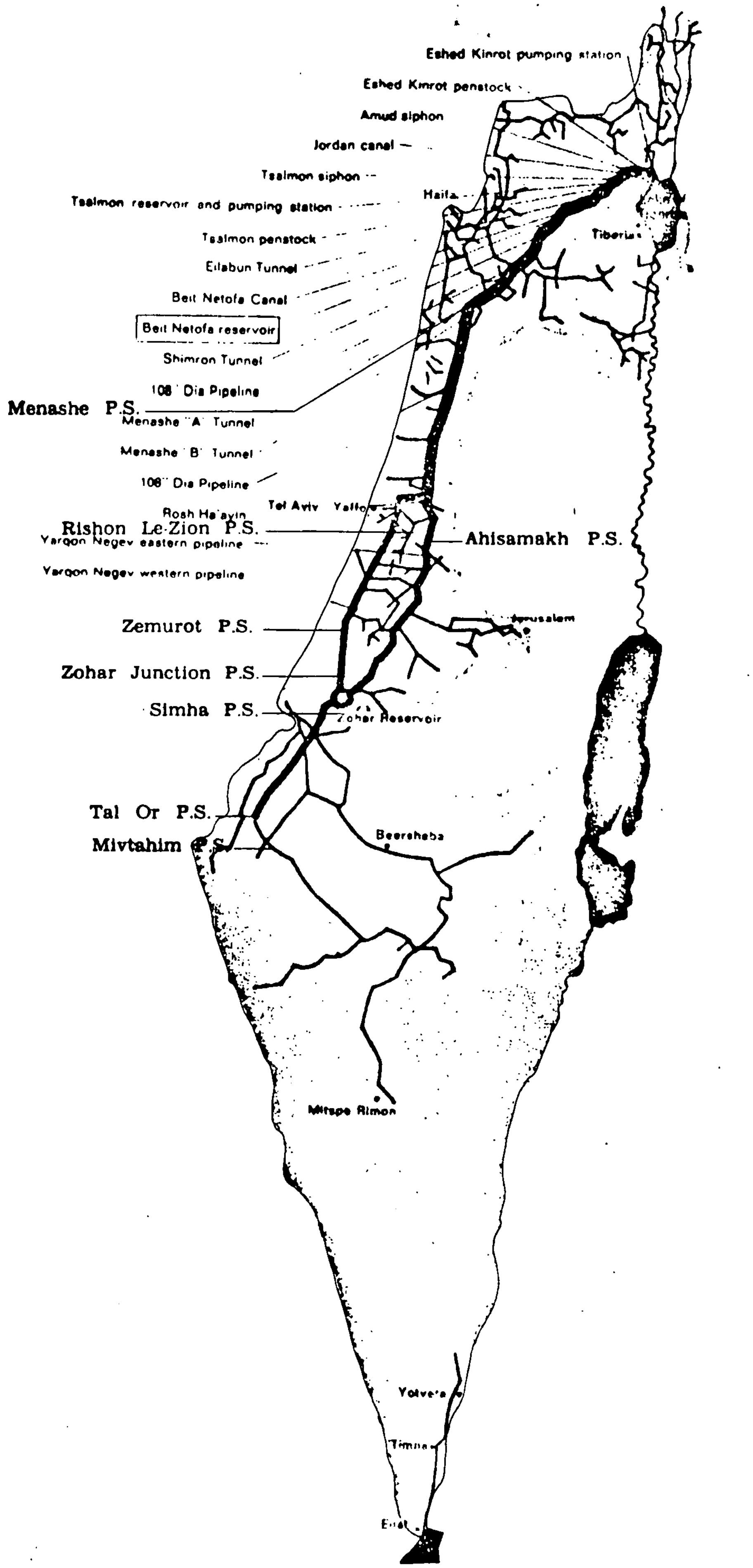
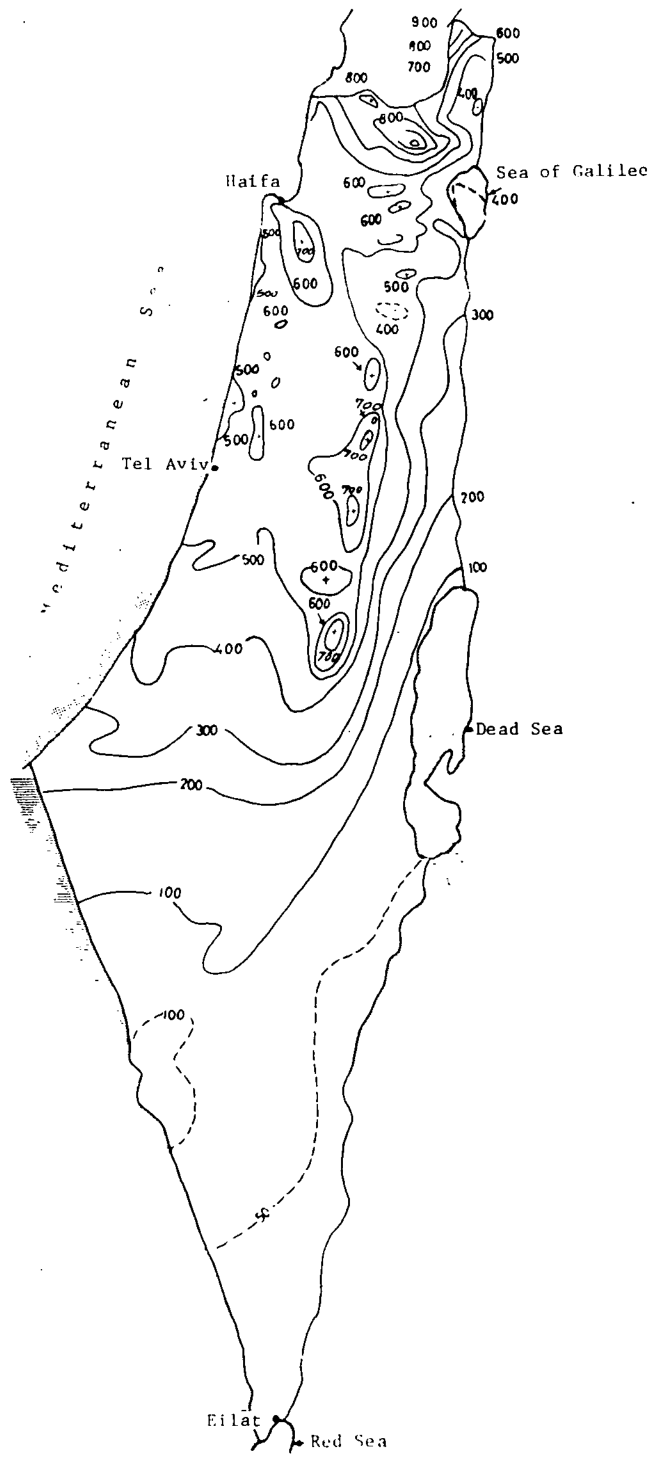


FIG. 1

	DEPARTMENT OF MINES – SOUTH AUSTRALIA	SCALE –
COMPILED. A.F.W	THE NATIONAL CARRIER SYSTEM OF ISRAEL	DATE Oct. 1977
DRN R.H. CKD.		PLAN NUMBER S13062



Data from Meteorological Service of Israel

FIG. 2

	DEPARTMENT OF MINES – SOUTH AUSTRALIA	SCALE —
COMPILED: A.F.W	AVERAGE ANNUAL RAINFALL FOR ISRAEL	DATE: Oct. 1977
DRN. R.H. CKD.		PLAN NUMBER S13063

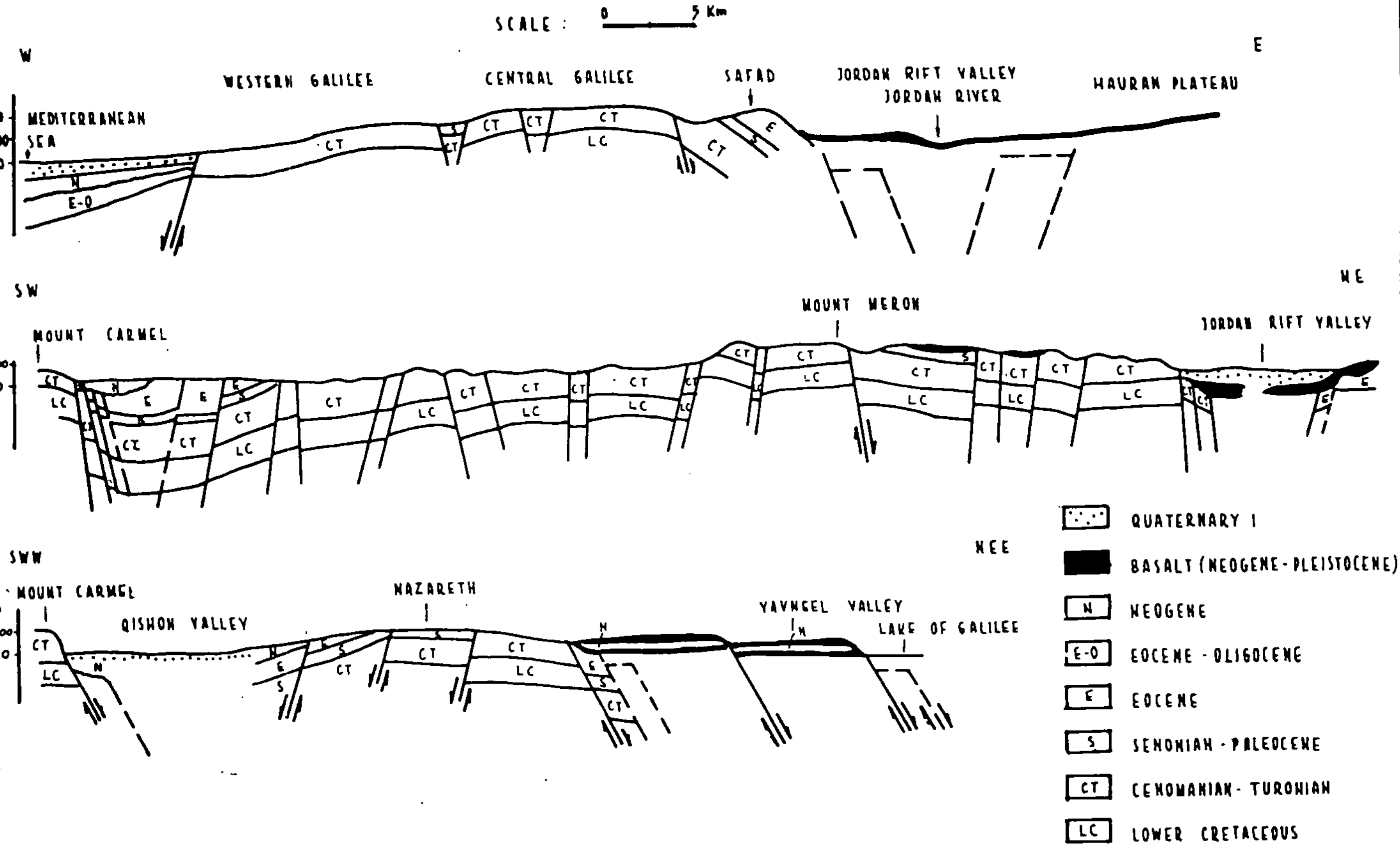
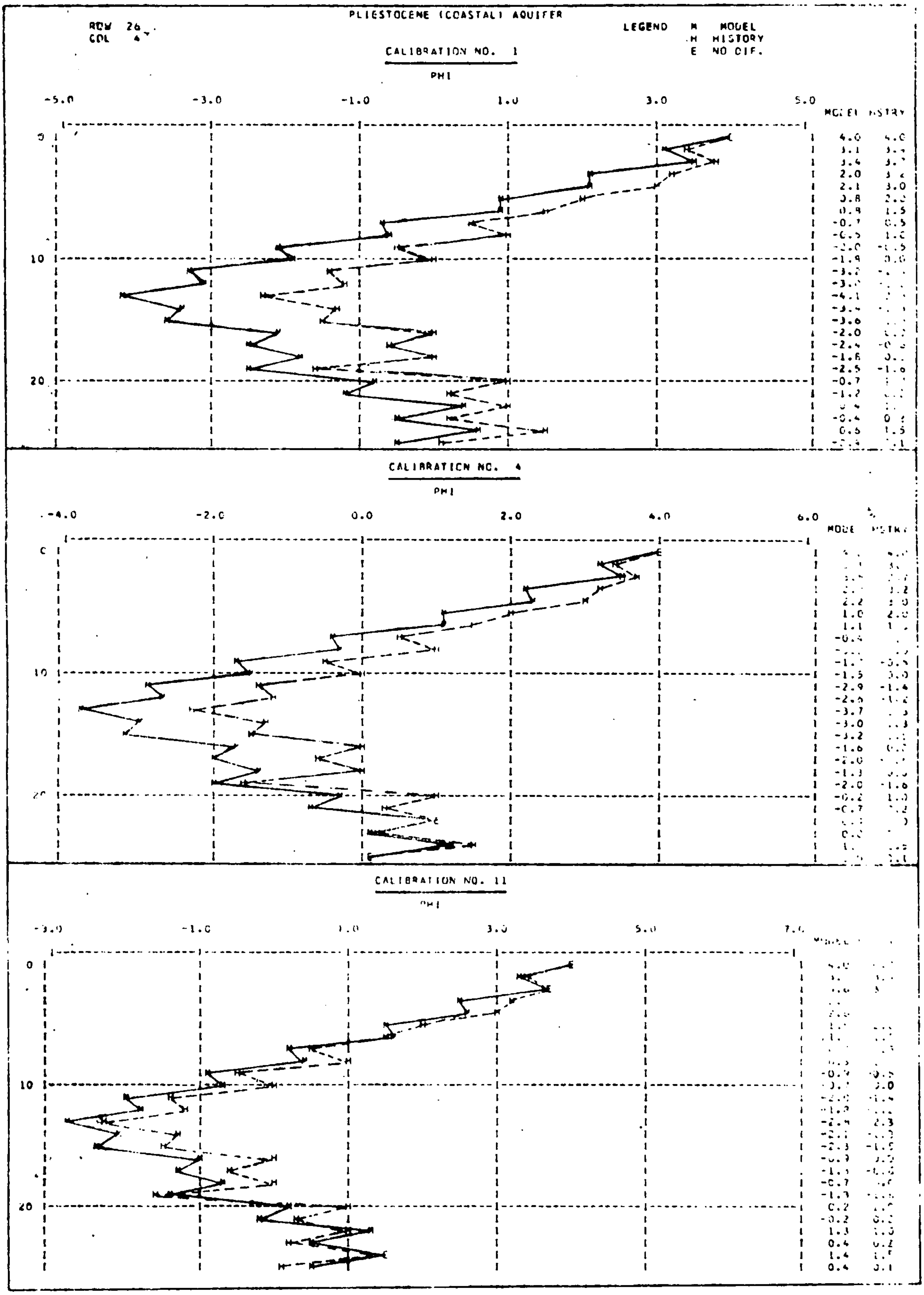


FIG. 3

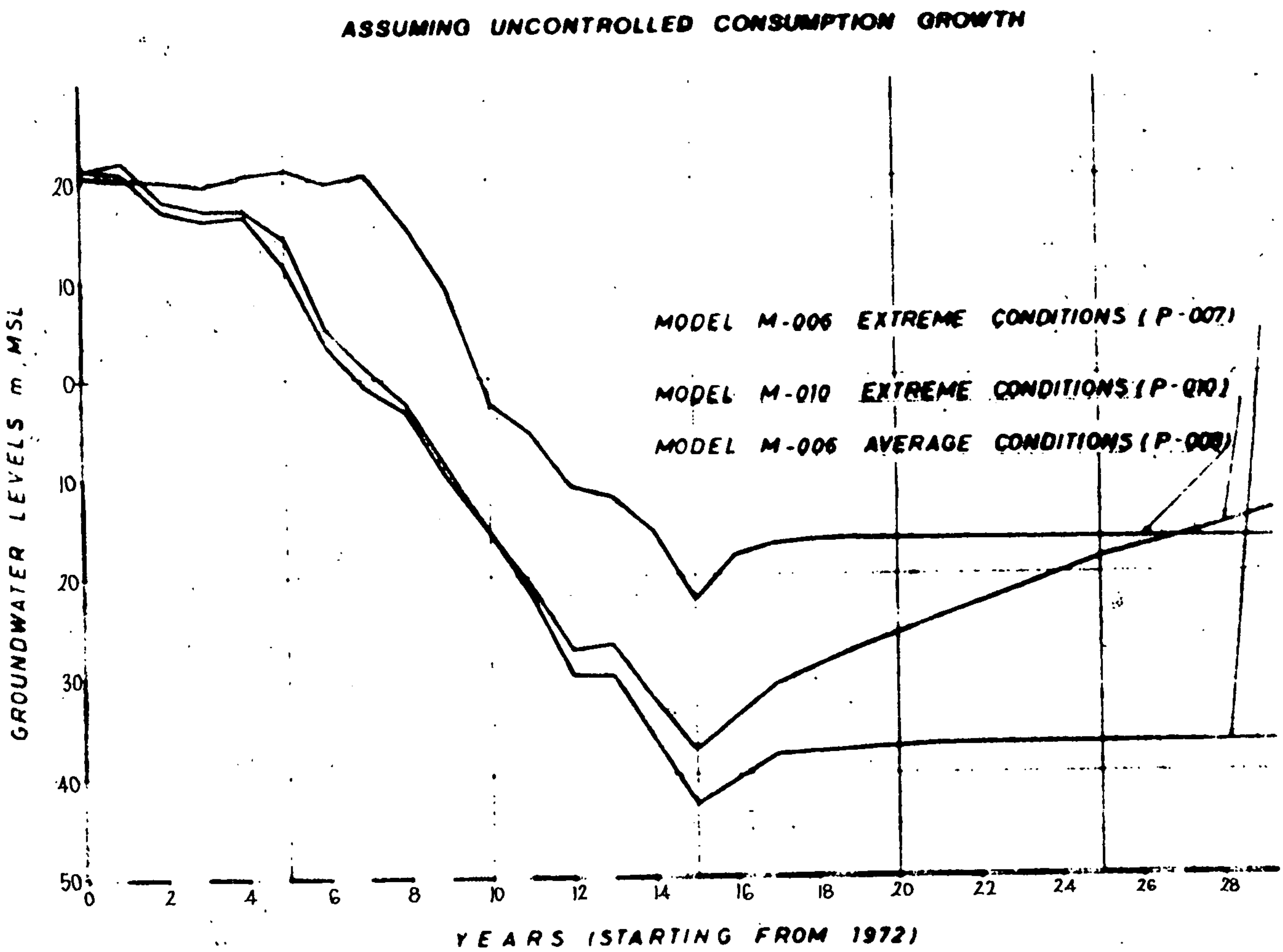
	DEPARTMENT OF MINES—SOUTH AUSTRALIA	SCALE: As shown
COMPILED: A.F.W.	GEOLOGICAL CROSS-SECTIONS THROUGH THE GALILEE, ISRAEL	DATE: Oct. 1977
DRN: R.H. CKD.		PLAN NUMBER S13064



COMPARISON OF COMPUTED TRANSIENT WATER LEVELS TO HISTORICAL DATA IN THREE POINTS FOR 25 SEASONS

FIG. 4

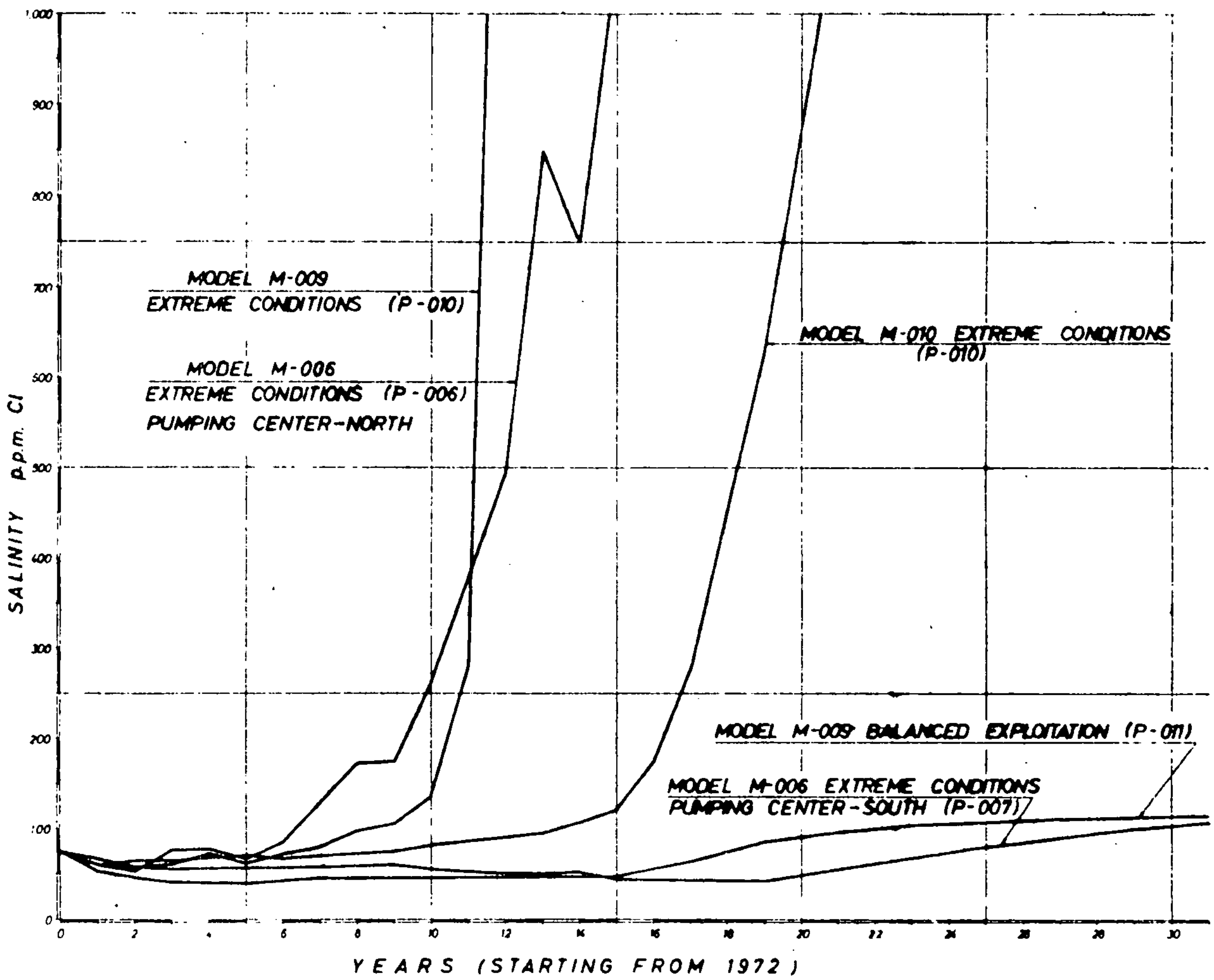
	DEPARTMENT OF MINES – SOUTH AUSTRALIA	SCALE: –
COMPILED: A.F.W.	CALIBRATION OF AN AQUIFER MODEL	DATE: Oct. 1977
DRN: R.H. CKD.	TAHAL – ISRAEL	PLAN NUMBER: S13065



M-006 NO SEA CONTACT
M-010 WITH SEA CONTACT
EXTREME CONDITIONS - 5% PROBABILITY OF EXCEEDANCE
AVERAGE CONDITIONS - 50% PROBABILITY OF EXCEEDANCE

FIG. 5

	DEPARTMENT OF MINES – SOUTH AUSTRALIA	SCALE: –
COMPILED: A.F.W.	FORCAST OF WATER LEVELS YARKON TANNINIM AQUIFER ISRAEL	DATE: Oct. 1977
DRN: R.H. CKD:		PLAN NUMBER: S13066



M-006 NO SEA CONTACT
M-010 } WITH SEA CONTACT
M-009 }
EXTREME CONDITIONS - 5% PROBABILITY OF EXCEEDANCE
AVERAGE CONDITIONS - 50% PROBABILITY OF EXCEEDANCE

FIG. 6

	DEPARTMENT OF MINES – SOUTH AUSTRALIA	SCALE. –
COMPILED: A.F.W.	FORCAST OF SALINITY YARKON TANNINIM AQUIFER ISRAEL	DATE: Oct. 1977
DRN. R.H. CKD.		PLAN NUMBER S13067

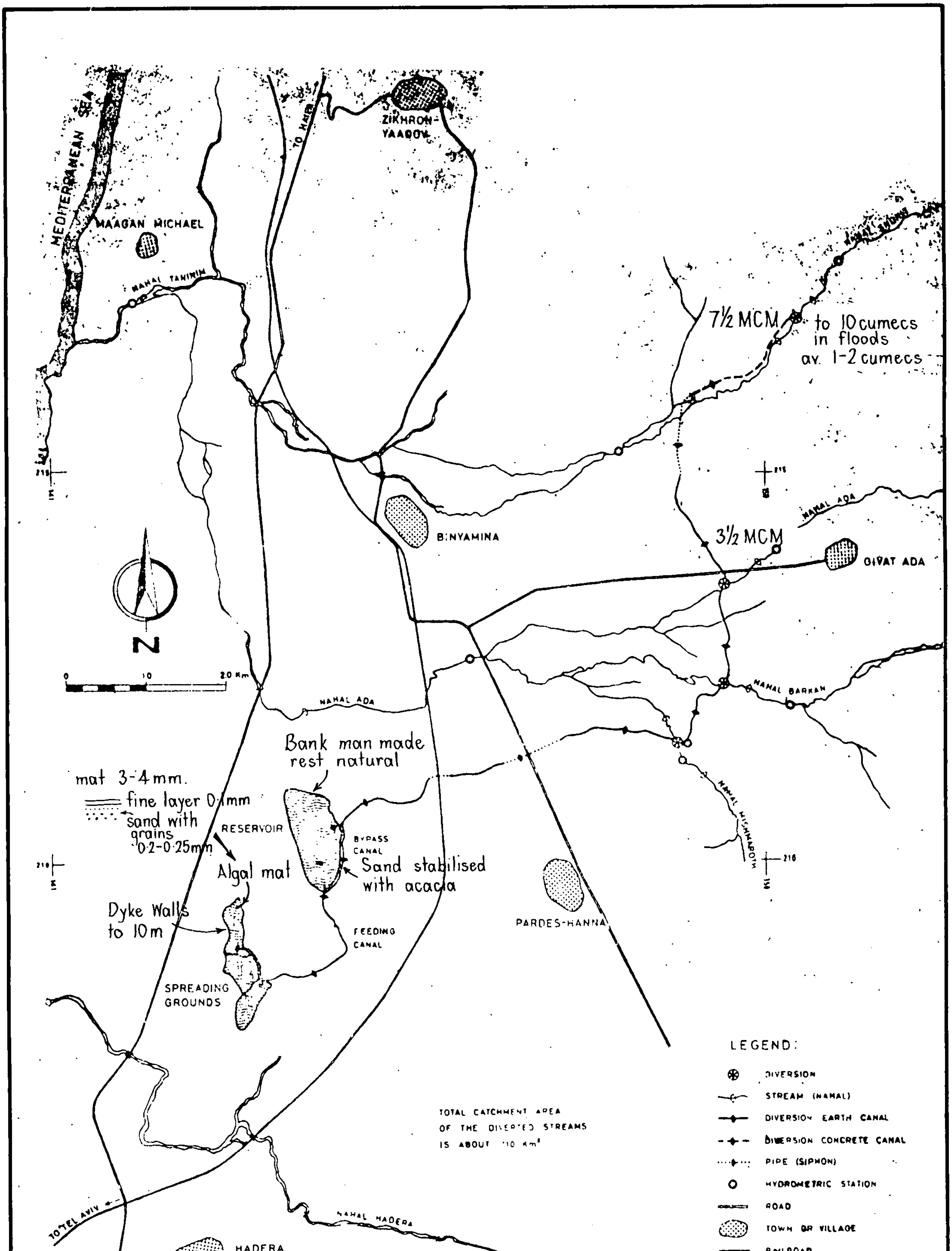


FIG. 7

	DEPARTMENT OF MINES – SOUTH AUSTRALIA	SCALE 1:75000 (approx)
COMPILED A.F.W.	NAHALEY MENASHE PROJECT	DATE OCT 1977
DRN R.H. CKD	GENERAL LAYOUT	PLAN NUMBER S13068

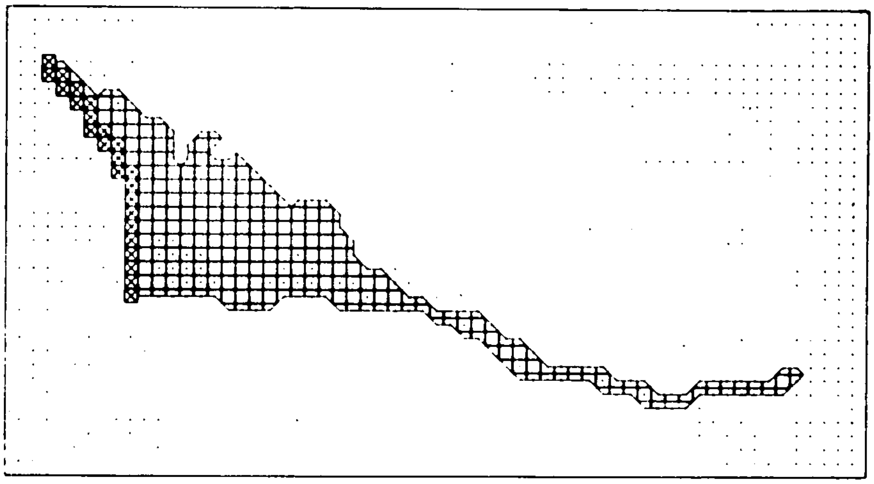


FIGURE 3a. Diagram Illustrating the Lateral Boundaries for the Moxee Valley Gravel Aquifer

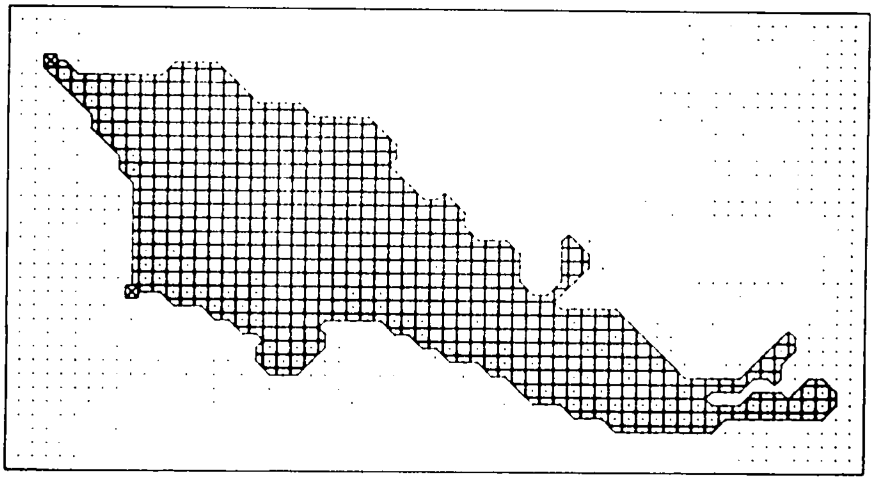


FIGURE 3b. Diagram Illustrating the Lateral Boundaries for the Moxee Valley Ellensburg Aquifer

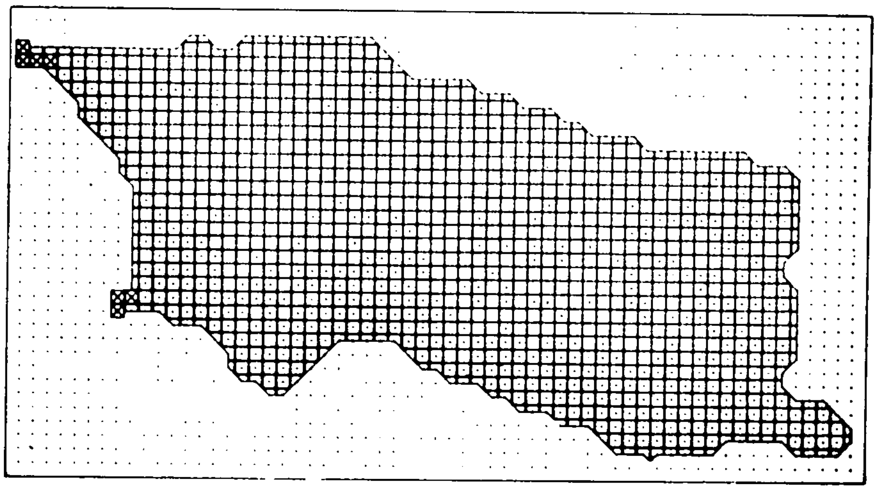
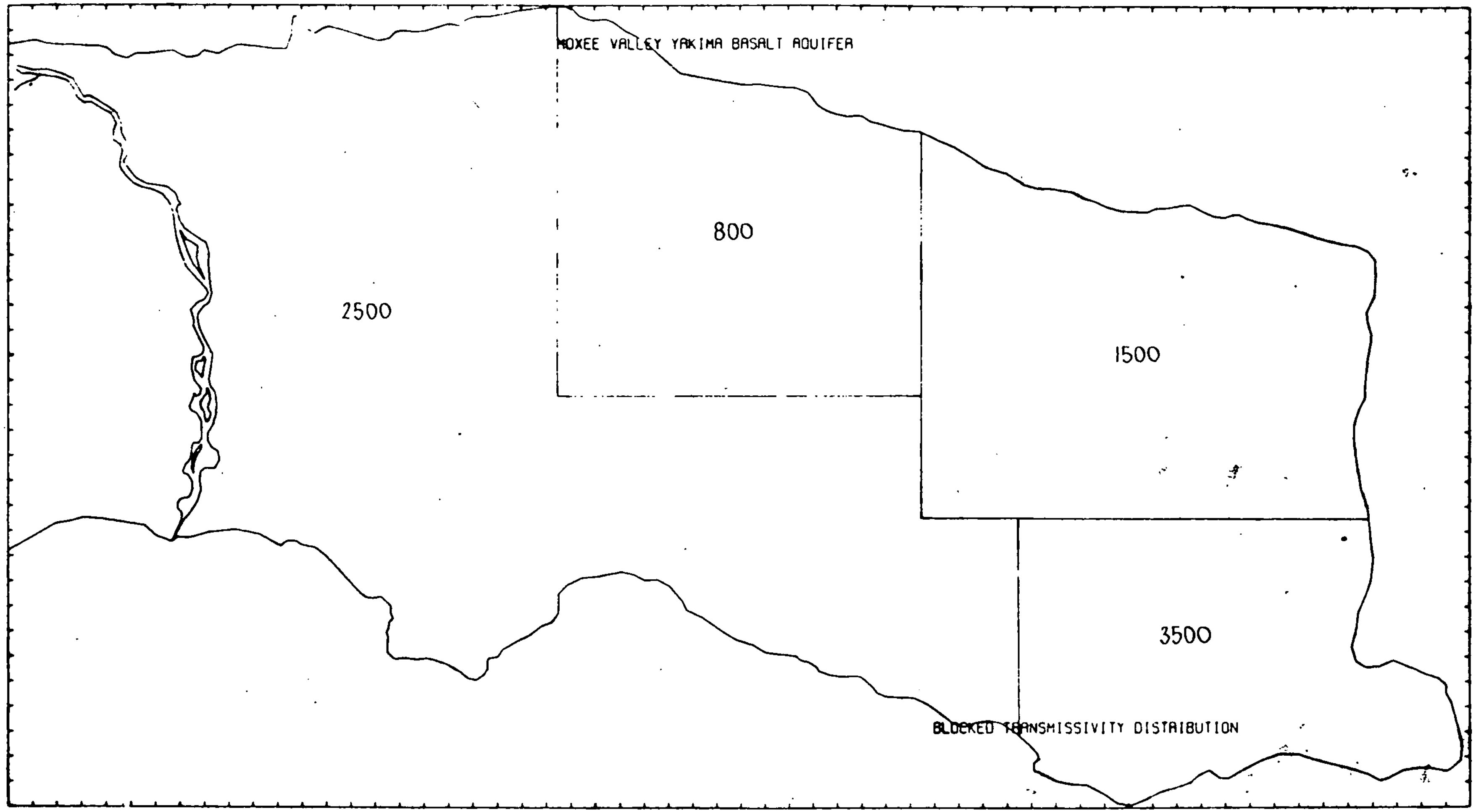


FIGURE 3c. **Diagram Illustrating the Lateral Boundaries for the Moxee Valley Yakima Basalt Aquifer** (see also Fig 9)

FIG. 8

		DEPARTMENT OF MINES – SOUTH AUSTRALIA	SCALE –
COMPILED. A F W		DIAGRAM ILLUSTRATING THE LATERAL BOUNDARIES OF THE THREE MOXEE VALLEY AQUIFERS WASHINGTON STATE	DATE Oct. 1977
DRN. R.H.	CKD		PLAN NUMBER S13069



Transmissivity values in Ft²/Day

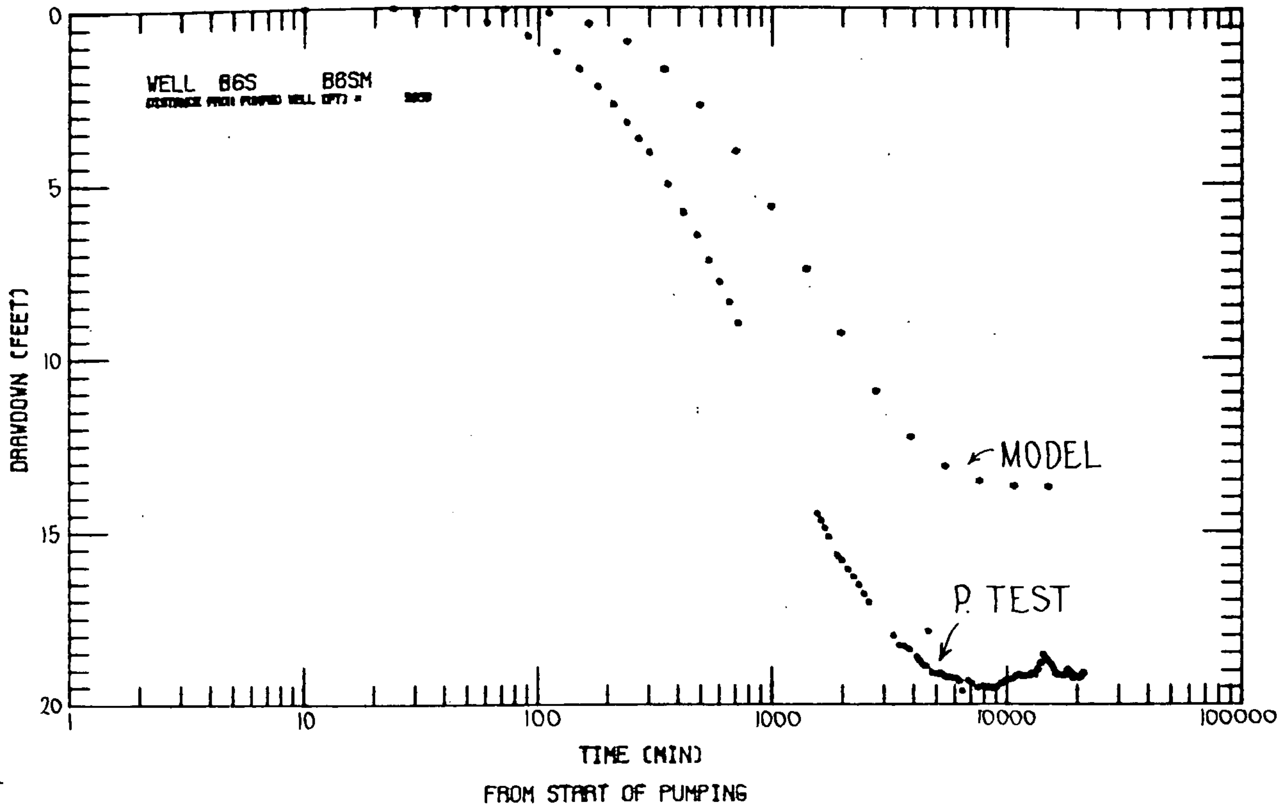
FIG. 9

DEPARTMENT OF MINES—SOUTH AUSTRALIA

AREAL DISTRIBUTION OF TRANSMISSIVITY
YAKIMA BASALT AQUIFER
MOXEE VALLEY

COMPILED.	A F W
DRN	R.H.
CKD	
SCALE	–
DATE	Oct. 1977
PLAN NUMBER	S13070

BATELLE, NORTH WEST LABORATORIES



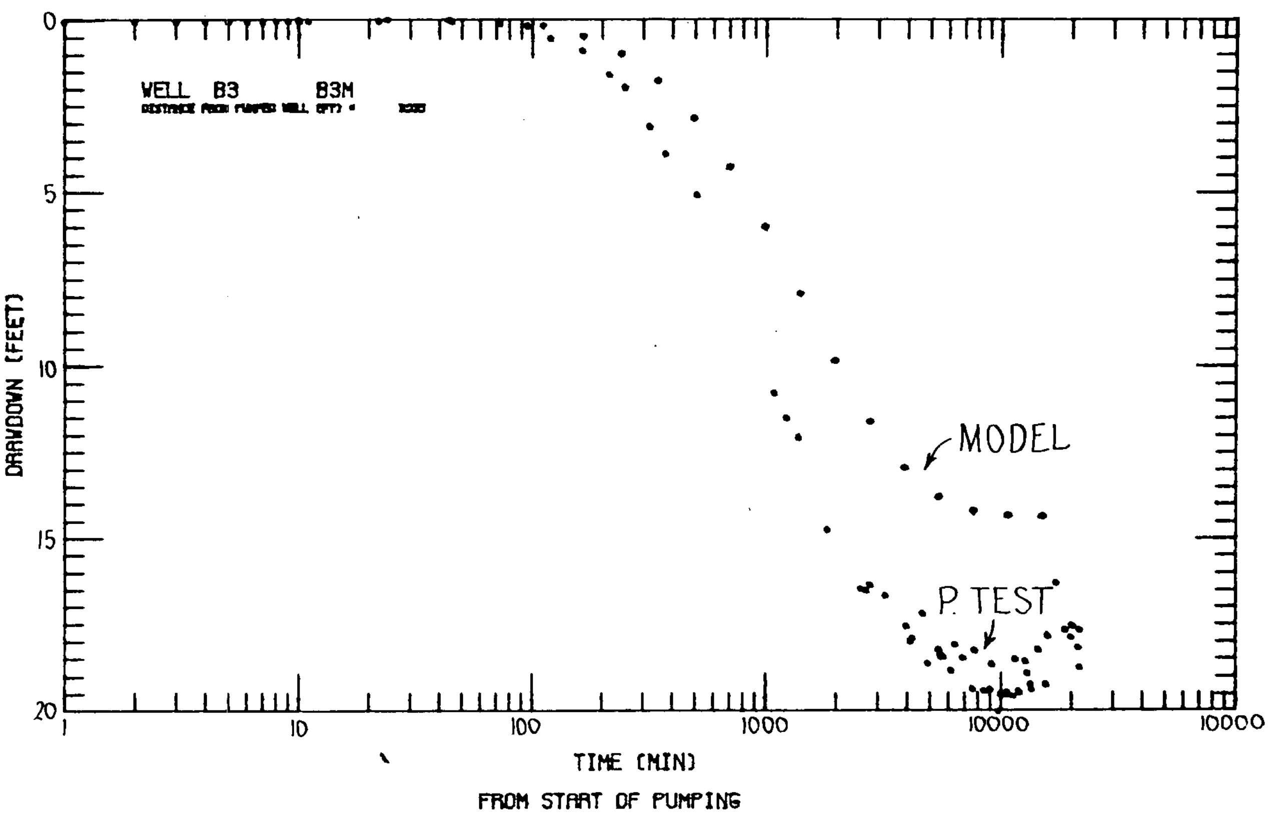


FIG. 10

	DEPARTMENT OF MINES — SOUTH AUSTRALIA	SCALE –
COMPILED: A.F.W	TYPICAL CALIBRATION RUNS - MODEL RESULTS COMPARED WITH ACTUAL TEST RESULTS, THEN MODEL REFINED TILL BEST AGREEMENT REACHED. HOOD CANAL AREA, WASHINGTON STATE	DATE: Oct. 1977
DRN. R. H. CKD.		PLAN NUMBER S13071