

Macleay River Water Quality Monitoring Project.

DESCRIPTION

Kempsey Shire Council has developed a unique environmental monitoring system to study water quality in the Macleay River floodplain below Kempsey. In this area, Acid Sulfate Soils were first identified in Australia and there is a long history of poor water quality and fish kills.

Several telemetred water quality probes have been installed along the Belmore River from the Macleay River upstream and in several other locations. The probes continuously measure dissolved oxygen, pH, electrical conductivity, temperature and depth and transmit the data back to Council's central computer for analysis. The gauges are also able to take physical samples for later laboratory analysis for Aluminium, Iron, sulphides or other toxic elements.

Already in the early months of operation of the system, improvements to water quality have been made by manipulating flood gates and previously bare acid scalds have been reflooded and grassed. It is hoped over a period covering several seasons and rainfall conditions that some pattern will emerge to enable a judgement to be made on the causes of water quality problems and identify some possible long term solutions. The system is also used to educate landowners in suitable farming practices for Acid Sulfate Soil areas and as a water quality management tool.

The system has been inspected by Dr. Ian White, Professor of Water Resources at the Australian National University and Technical Consultant to ASSMAC, who praised the system as "adventurous and innovative" and of "world class".

INTRODUCTION

Kempsey Shire Council has developed a unique project to study water quality in the Belmore River, which is a tributary of the Macleay River below Kempsey. In the past, fish kills have occurred in this and other areas of the Lower Macleay, which appear to be related to rises in the River level, discharges from Acid Soil areas and operation of the Flood Control system.

Several water quality probes have been installed along the Belmore River from the Macleay River upstream and in other locations. The probes continuously measure dissolved oxygen, pH, electrical conductivity, temperature and depth and transmit the data back to Council's central computer. Other gauges measures rainfall in the area. The gauges are also able to take physical samples for later laboratory analysis for Aluminium, Iron and sulphides.

The project is sponsored by the Macleay Estuary and Coastline Management Committee and is supported by the Macleay Total Catchment Management Committee (TCM) and the Macleay Acid Sulfate Soils Local Action Group (MASSLAG). There is very broad community support for the project from farmers, fishermen, environmentalists and administrators. The Department of Land and Water Conservation and Council see the project as the key to improving water quality in the Macleay and other coastal rivers by providing a high level of instantaneous knowledge regarding water parameters and options for flow control.

BACKGROUND

Much of the Macleay River flood plain downstream of Kempsey was once a coastal lagoon which over the last 10,000 years, with a lowering of sea levels and an influx of sediment has become drier. In this environment, soils which contain iron sulphides (mostly pyrites) or their oxidation products are produced and are commonly called acid sulphate soils (ASS). This process still occurs in wetlands, coastal lakes, swamps, etc today and is a natural and continuous process along the entire east coast.

In 1963, Dr. Pat Walker of the CSIRO, identified ASS, then called "cat clay", in the Belmore River area. It is believed this was the first time the phenomenon had been identified in Australia. Despite this early discovery, it has only been in the last few years that the full mechanism and impacts of ASS reactions has become known.

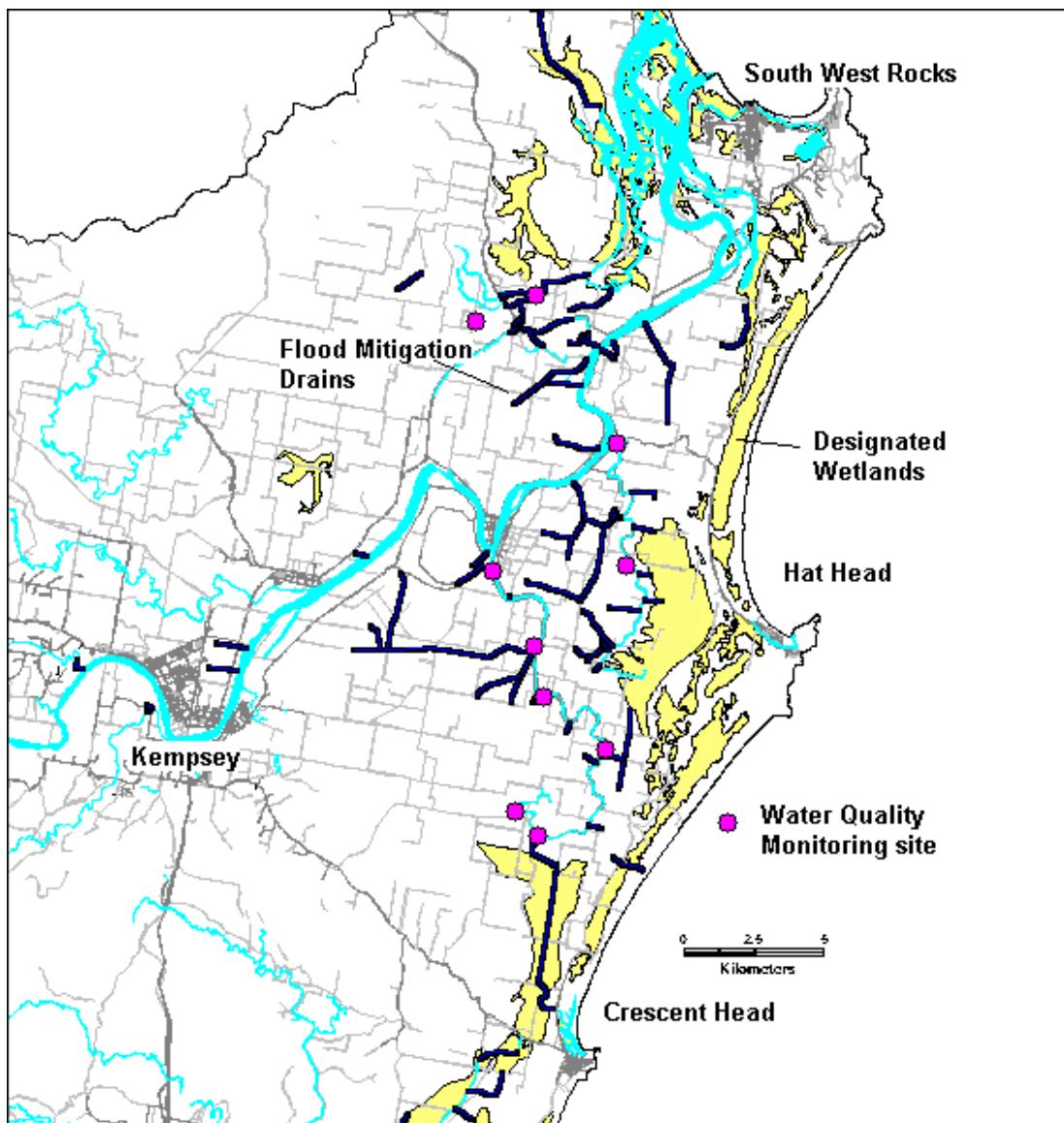


Fig.1 Map of Lower Macleay River showing project location.

When ASS is exposed to the air, oxidation to form sulphuric acid occurs. Formation of the acid leachate is obviously very harmful to aquatic life and vegetation, especially during dry periods when high concentrations can accumulate in streams and back swamps. Local recordings of pH below 3.0 are not uncommon in some drains (it is considered pH below 4.0 is toxic, while pH below 6.5 will cause problems for aquatic species over long periods).

There are numerous signs of the presence of acid sulphate soils in the Lower Macleay. These include the presence of stunted vegetation and indeed total lack of pasture from some areas, deposits of yellow jarosite near the surface, red or brown discolouration of the water and corrosion of concrete, iron and steel structures. In many areas acid affects have reduced the viability of the local dairying, grazing and cropping activities.

In addition to the direct effects of acid on species, toxic elements such as aluminium, iron, copper, manganese and cadmium may be dissolved from the soils at low pH to be released into local waterways. It has been observed that an acid leachate when entering a waterway may cause a flocculation of suspended sediment. This can lead to a characteristic clearing or "milkiness" of the brackish water as aluminium is precipitated out with a rise in pH. A red scum of iron oxide is also common.

Deoxygenation of water by chemical reactions involving iron may also affect species in these areas and compounds the loss of oxygen from the water by vegetation rotting after a flood.

Council is involved with several local community and environmental action groups to promote education about ASS and reduce the impacts of it.

FLOODING AND FLOOD MITIGATION

The Macleay River catchment has an area of 11,500 square kilometres, including a large tablelands area. High intensity rainfall in the upper catchment combined with steep grades can produce dramatic stream rises in a short period. In 1949 and again in 1950, floods of 1 in 100 year recurrence interval occurred, causing significant damage and loss of life. In 1963 a 1 in 20 year flood occurred.

Following those major floods there was significant pressure to provide some flood protection for the major towns in the flood plain and the Lower Macleay rural area. A flood mitigation scheme was commenced in the 1950's and completed in the 1970's with the aim of:

- protecting Kempsey in a 1 in 20 year flood,
- protecting the lower Macleay agricultural areas from a 1 in 3 year flood,
- allowing rapid drainage of flood waters from inundated farmland.

The scheme for which Kempsey Shire is now responsible has a value in excess of \$50Million and consists of 87 flood gates (including three major control structures), 116 km of drains and 180 km of levees and bank protection. The levees have had the effect of reducing nuisance flooding over most of the lower Macleay. Land previously affected by a 2.5m AHD flood is now unaffected up to 5.2m AHD. To achieve this protection, during a minor flood (between 4.1m and 5.2m AHD), it is necessary to discharge flood water through control gates into natural swamp depressions. This sacrifices some poor agricultural land to protect more valuable upper levee land.

While this philosophy was apparently accepted when the scheme was designed in the 1950's, today with many different pressures upon farmers and changes in farming methods, operation of the scheme in this way is very difficult. This difficulty has been exacerbated by long recent dry spells, subdivision of farms, an influx of new residents and different community attitudes. Local farmers believe opening of the flood control gates unfairly "dumps" water upon them.

In an effort to address some of these community concerns, Council recently completed the Lower Macleay Flood Plain Management Study (Webb, Mckeown & Ass, 1997), which was a "holistic" examination of the flood mitigation scheme, and the environmental, community and social impacts of it. The Study included extensive public consultation and examined options for improving operation of the scheme and increasing flood protection, and also sought to remedy perceived shortcomings of previous works or practices.

There were a number of recurring community concerns particularly regarding the relationship of "fish kills" to operation of the flood mitigation scheme and "equity" of flood protection for all lower river properties. Among the Study recommendations was that further research be carried out into the factors causing fish kills and a suggestion that some flood levees (along Kinchela Creek and Belmore River) should be raised slightly.

In hindsight, it was recognised that many of the swamps were overdrained and drains were excavated too deep through acid sulphate soils. Many of the farmers complained of the loss of important wet-pasture species and wanted to "keep the wetlands wetter", although they still wanted to drain off this "dumped" flood water.

Raising of the Kinchela Creek levees and a small section at Belmore River, would allow a drastic reduction (estimated at 90%), in the number of times it was necessary to open the flood control gates, and thus reduce the "unnatural" flooding of the low swamp basins. It was theorised that Council and landowners would have more control over these swamp areas and they would not be subject to the extreme wetting and drying actions which now occur. In addition, to ensure levels of the swamps and the soil water table were maintained, it would be necessary to alter gates on some farm drains to allow water back into the swamps during dry periods and also perhaps to make "environmental releases" from the flood controls during small freshes in otherwise dry periods. Monitoring of the water levels and quality in these areas would be necessary for this to succeed.

FISH KILLS

In the past, fish kills have occurred in this and other areas of the Lower Macleay, which appear to be related to rises in the Macleay River level and operation of the Flood Control system. Fish kills have also occurred during dry weather (possibly due to algae and deoxygenation) and in minor rises when the control gates have not been opened. Historical evidence also indicates that major kills occurred prior to any flood mitigation works being constructed.

When these kills occurred, Council invariably took samples of the fish and the water for analysis and had to clean up the mess. Test results were usually inconclusive due to the passage of time from the trigger for the mortality and the sampling, however low dissolved oxygen (DO) was often apparent with low pH. Council usually expressed the attitude that kills were mainly caused by deoxygenation of floodwaters due to rotting vegetation in the swamp margins.

Fish mortality seemed to be worse if a flood occurred after a long drought or it was followed by hot weather.

From observations, the principle mechanisms for fish kills appeared to be;

- deoxygenation of waters due to rotting vegetation (perhaps combined with temperature increases)
- the release of acid water from ASS into drainage channels and streams
- physical flushing of fish through the control gates during a flood out into open, shallow swamps.

Following several major mortalities and increasingly adverse publicity, and in accordance with the recommendations of the Flood Study, in early 1997, Council sought water quality monitoring equipment to install in the flood plain which would provide sufficient information to suggest actions to improve the situation. It should be emphasised that quality of water for stock and pasture were also concerns as well as for fish habitat.

EQUIPMENT SELECTION

Council operates a sophisticated flood warning (ALERT) system, which utilises a network of stream level and rainfall gauges throughout the upper catchment and lower flood plain. These gauges send data by radio telemetry back to a central computer in the engineering office. It was hoped to install the new water quality monitoring equipment to be integrated within and compatible to the existing flood warning system.

It was apparent that continual (real-time) monitoring of the key water quality parameters leading up to and following a flood event was essential to ascertain the relationship between the floods, outflow from various drains and effect upon aquatic life and pasture.

Other necessary equipment criteria were:-

- accurate, reliable probes for acidity (pH), dissolved oxygen (DO), electrical conductivity (Ec, salinity), temperature, level (pressure) and possibly turbidity
- the ability to take samples at set triggers or at set intervals for later testing for toxic elements
- robust probe equipment able to withstand very harsh water environment
- robust equipment housing able to withstand flooding, debris and cattle interest
- minimum of maintenance to probes and housing
- solar powered with battery recharge
- adequate telemetry equipment for purpose.
- compatibility with existing flood alert system
- data easily accessible and able to be archived.

Following inquiries it appeared that this type and extent of environmental monitoring had not been undertaken before in Australia over such a large area. Greenspan Technical Services, provided indicative quotes, specifications and technical advice and were chosen to develop a trial system.

Funding of \$100,000 under the Department of Land and Water Conservations' Flood Plain Program was obtained for the proposal in 1996 and Council contributed \$50,000. Additional funding of \$100,000 was obtained in 1997 under the 2:1 subsidy scheme.

EQUIPMENT DESIGN AND INSTALLATION

It was decided, that as Belmore River was the site of the worst fish kills, a pilot monitoring

program would be implemented there. Following a minor flood in February, 1997, (5.0m at Kempsey, during which the control gates were opened briefly) temporary "sondes" with data loggers were placed at Union Drain and Scott's Drain. These drains were thought from observation and some previous testing to contribute poor quality water to the river. This allowed a check on the recovering river above and below flood headworks, while the permanent equipment was imported from America and the final system was designed.

The first permanent installation was at the Belmore River junction with the Macleay where an existing flood gauge was adapted. Five other freestanding sites along the Belmore River (a distance of 18km) were chosen. The sites chosen were intended to cover a range of conditions, at major drains, the flood headworks or at critical locations with known problems. An important consideration for site selection was to ensure good water mixing occurred to reduce the effects of stratification. One of these stations was to be trailer mounted to allow easy movement, with the remainder semi-permanent. In addition another existing flood gauge at Kinchela Creek was to be converted for water quality monitoring to act as a river control.

To allow for tidal and flood level fluctuations, a floating arm for the Greenspan water quality probes (pH, DO, Ec, temp) was designed. These four probes are housed within a Delrin body of about 200mm diameter, with each probe head removable for cleaning or replacement if required. The Delrin body is contained within a PVC sleeve and suspended from the floating arm. Trial and error of various probe depths and consideration of effects of bottom mud and debris later set an acceptable range. As we were more interested in the mobile surface layer to indicate if water was suitable for stock, was saline, or had sufficient oxygen and as much of the upper end of the river was shallow, a probe depth of about 900mm below the surface was adopted. The floating arm overcame the problem of probes being exposed to the atmosphere at low tide and ensured readings were taken in a consistent water strata.

The water level is obtained by a fixed-position pressure probe, levelled in to AHD. All probes are connected by sheathed cable to the station control box. Data is transmitted for each of the five parameters (ie, pH, Ec, DO, temp and level) every 15 minutes from each of the seven current stations, via an ELPRO AWS ERRTS canister back to the central computer. Rainfall data is transmitted when recorded. The system is powered by SLA batteries charged by a solar panel through a regulator.

In consultation with Council, Greenspan designed and fabricated a monitoring station for the four (4) other free-standing sites. This station is of very sturdy steel frame and sheeting, with a good working platform and is raised above likely flood level. The station is lockable and very secure, although as most of the stations are on private property with the support of the landowner, vandalism is unlikely to be a problem. The stations are designed to be demountable for transportation in a utility to other sites. One of the stations is mounted in a small box trailer to ease movement. This station contains the full complement of logging and sampling equipment plus its own solar panel and telemetry gear and also carries a range of spares, materials and tools for maintenance. All five of the original freestanding sites were equipped with "Sigma 900" automatic samplers, which allow the collection of samples at some pre-set trigger (ie pH<4.0, DO<6, etc) or at regular intervals. The sampler is equipped with a peristaltic pump and up to 24 samples can be stored for later laboratory analysis. The unit has its own data logger and battery and can operate independent of the main data recorder.

One of the stations has also been fitted with an automatic tipping-bucket rain gauge to supplement local rainfall records. Council has also purchased an additional "Sonde" monitor which can log and record pH, Ec, DO, temperature, level and turbidity and which can be positioned for short periods in drains or "hot spots" or to calibrate the main loggers.

The data is collated for all stations and parameters into one data base on a PC for analysis. Using the computer software created it is possible to view the data from each station for any period from 15 minutes to a month or longer, or to view a single parameter from all stations (ie, all pH, all DO, etc). It is also possible to graph all parameters concurrently or selectively on the screen and to print the graphs. Data is archived monthly and converted using the "Hydsys" program to remove spikes and present the data on disc and in printed form..

The system can be accessed remotely via a modem and data can be read directly from the stations if necessary.

PROBLEMS ENCOUNTERED

The current system at Belmore River has now been in place since May 1997 and excellent results have been obtained. It would be fair to say that the actual probes have performed extremely well, with negligible errors and little need for replacement or re-calibration. Some minor problems in data transmission and positioning of the sites have had to be overcome.

When the temporary sondes were placed (fixed to stakes in the water) they were often exposed at low tide. This was overcome by use of the floating arm.

The severity of the water environment had been underestimated and while the probes and their delicate reading membranes were not damaged by the water, heavy cleaning and maintenance was necessary more often than anticipated to maintain accuracy of the readings. It was originally intended, that apart from brief inspections, major cleaning would be undertaken at only two to three-monthly intervals. Due to the heavy build-up of iron oxide on the probes this has been shortened to monthly intervals. It was found that the longer period caused a very heavy build-up which reduced accuracy of readings and made cleaning difficult. There was a danger that the delicate membranes would be damaged during the cleaning process.

Due to the intrusion of salt in the upper Belmore (Scott's Drain) it was necessary to adjust the reading range of the Ec probe to an upper limit of 50,000 $\mu\text{S}/\text{cm}$. High salinity was also evident at the Kinchela gauge (which is the closest to the ocean) during dry times.

Due apparently to the very flat terrain, the number of stations relatively close together, the frequency of signals and clashes with signals from the other flood alert stations, there were initial problems of "spikes" and corrupt data being received. An additional, stronger radio signal reception canister was placed at the radio base which has greatly improved the data. In addition, signal transmission from each of the stations was offset in time slightly to reduce clashes.

Sampling has not been as necessary as originally envisaged and it is not intended to add a sampler to all future stations. It should be possible to distribute samplers so that representative results are obtained. Samplers may be used as free-standing monitors in some cases.

As the water quality system was required to be compatible with the existing flood ALERT

system, and accessible to the Bureau of Meteorology and Department of Land and Water Conservation by modem, it was necessary to use the QNX computer language and programs for data storage. Although this gives good data compression and good output from a QNX computer, it limits remote access by other DOS or Windows based computers and graphs cannot be viewed remotely. Recently the base station has been converted to a new Windows – based system. This has provided remarkable ease of access and it is now possible to view, edit or interrogate the parameters of any of the current sites. Graphs in colour can be generated for any parameter or groups of parameters or for all parameters at each site. This will simplify access for the many interested farmers and academics as well as Council staff.

RESULTS OBTAINED

As mentioned most of the system has only been operational since May, 1997, with some temporary arrangements in place prior to then. At time of writing there had not been sufficient rainfall for a flood fresh or a significant rise in river level to fully test the arrangements. There have also not been any apparent fish kills or major environmental incidents although there was a strong algal bloom in December, 1997.

Results to date in the Belmore River indicate a strong variation in quality over its length. Following the mid-February flood the river was very turbid (chocolate brown) for about three months. This is apparently due to high iron and low oxygen content and the sediment load retained in suspension. A brief analysis of the results can be made by dividing the river into upper and lower reaches, divided by the flood headworks. (*See Appendix A for graphed results*)

In the lower river following the flood, DO levels were almost zero and constant, Ec was less than 200 uS/cm (ie fresh water) and pH between 5.5 and 6.0. Tidal action was noted to affect pH and Ec but not DO. Incoming tide caused pH and Ec to raise with a corresponding fall as the tide ran out. While DO remained very low until May, pH gradually fell and Ec gradually increased as the water cleared and tidal flushing was more effective.

In the upper river, DO increased more rapidly with time (from zero in March to 5.0ppm in late April) while pH increased gradually to 6.2 and Ec climbed to 3000 uS/cm in a month. In this area tidal variations were more noticeable and it was apparent that there is a salt source. At low tide the flap on the Scott's Drain opened and discharged water with higher DO and salinity into the Belmore River. Acidity (pH) also changed with the tidal outflow, however it appeared this was being buffered by the salinity.

In June, in the lower river (Union Drain), pH had settled between 5.0 and 5.5, DO around 10ppm and Ec around 2000uS/cm. In the upper section pH was less than 4.0, DO was 5.5 and Ec was about 1400. These results would appear to be typical for the Belmore River in normal conditions. Some changes occur with very hot temperatures and in extremes of tide. Readings of pH down to 2.9 and Ec up to 18,000 have occurred at Scott's Drain.

It was considered that the main source of salt getting into Scott's Drain was leaking gates on an ocean flood outlet some 10km south at Killick Creek, Crescent Head. Repair of that gate has reduced the salt level but not eliminated it. It is possible that there may be a source of salt in soil or groundwater which is still contributing. The presence of the salt certainly complicates the issues and makes dealing with the farmers very difficult.

The preliminary results to date have revealed:-

- different actions and flows occur in the upper and lower sections of the river,
- water quality at the mouth of the Belmore River and in the Macleay is excellent and fresh most of the time

- outflow and mechanism of each drain is different and needs to be examined separately
- recovery after a flood is very slow
- interaction of causative factors is complex and will require close scrutiny
- concentration of aluminium and iron is often very high
- the quality of water from Scott's Drain and Union Drain is poor during dry periods
- poor tidal flushing of the river hampers recovery after an event
- duplication of flood headworks to provide greater waterway may assist flushing
- saltwater intrusion buffers the low pH in the upper reaches and causes other problems
- larger fish species return to the river well before smaller more sensitive species

Full analysis of the results and suggested actions will require specialist consultant or academic study which is currently being organised. Even a preliminary analysis and present actions have indicated the value of the system for environmental water control.

To ensure the study is as effective as possible, Council is also carrying out physical fish counts or inspections in the river at regular intervals.

ACTIONS TAKEN

The knowledge gained so far of the water quality in the Belmore River and other lower Macleay areas, has allowed improvements to be made to the soil and pasture in adjacent properties and in the swamps and drains. In the Scott's Drain area, a large bare acid-scalded patch has been rehabilitated back to useable pasture by opening the drain gate and flooding the area. This has flushed the acid and salt residue from the patch and allowed wet pasture grasses to grow. Opening the drain flap when the river water was known to be better quality than the swamp water has also pushed the salt water back off much of this affected land and stopped the saline discharge from the drain.

In the Union Drain area, and at Kinchela we have been able to open drain gates to replenish low water levels and replace poor quality stock water with fresher water. Obviously this must have some benefit for fish species as well as for cattle and farmers.

Use of the system has been warmly welcomed by local landowners, who can see that Council is doing something practical about their problems and is deflecting the criticism of the "fish lobby" away from the flood mitigation system and themselves. Farmers are very knowledgeable regarding acceptable salt and pH levels and regularly inquire as to the levels in the river near them. This helps them to operate some small drainage flaps and pumps for their benefit. Many farmers have computers with Internet connection and they will soon be able to seek out the data for themselves from an open Web page or modem. Data is also linked to councils flood warning system and integrated with 17 rain gauges and 14 river height gauges in the Macleay catchment.

The system has also been welcomed by local oyster farmers, professional fishermen, Dept of Fisheries and academics as their interests are being protected and the data base created will assist their research. Local environmental and action groups such as MASSLAG are encouraged by the innovative system.

FUTURE ACTIONS

As mentioned, over a period of several seasons, specialist consultant or academic study of the data will be required. Council is currently seeking interest to undertake this work. Using the data, refinements to the operating methods (timing of openings, inverts of drains, etc) of the flood

mitigation system will be made and changes to farming practices suggested.

Data will be collated for all gauges and parameters into one data base for analysis and made available on a Web page and on CD-ROM to farmers, fishermen and academics. University graduate students and academics will be encouraged to analyse the data. An education program for farmers, school children and the general community will also be implemented around the gauge output. The current project has received a great deal of support from landowners and all associated authorities. Weekly newspaper reports of criteria may be made.

Council intends to set up management groups in each major wetland, swamp and drainage area. On these groups will be landowners, Council, technical experts, Depts of Agriculture, Fisheries, DLWC, National Parks, oyster growers, fishermen, etc. Each group will set a "desired" water level to allow for pasture growth, fish nursery, wildlife, acid soil coverage, etc. This will be an optimum level to suit most needs. Other criteria of pH, DO, etc may also be set. It is hoped that an automatic telemetered monitor will be set up in or near each groups area of interest to enable them to gauge the water level and quality. When level gets low or quality is poor, (in time of drought or other) the group could request farm drain gates to be opened or for flood control gates to be opened when there is a fresh in the river. If landowners are reluctant to raise water levels, Council may implement a Development Control Plan or other regulation to apply force.

Group studies may dictate changes to flood mitigation methods or local drains to improve water quality, etc. This will be a long term process throughout the Lower Macleay and may take years to establish but is the answer to current problems.

Council is also initiating a Local Environmental Plan to cover development and management of ASS affected-land in the Shire.

Further funds of \$100,000 were approved under the DLWC Flood Plain Program for 1997/98 to purchase more equipment and to assist with maintenance. Other funds are being sought from National Heritage Trust and other sources to expand the program .

Indicative costs of between \$17,000 and \$20,000 apply to each new station, dependent upon site conditions and components included.

CONCLUSION

The water quality monitoring system at Belmore River has been a pilot project to allow the bugs to be sorted out and refine the needs. Already at Belmore over 12 months we have enabled grass to grow over acid scalds by keeping it wet and by keeping salt and acid water off it. With manipulation of farm drains as indicated by poor water criteria (low pH, DO, etc) it has been possible to greatly improve the overall water quality in the Belmore River for the benefit of fish and farmers.

The original intention was to relocate all the Belmore gauges after a period of several seasons. The value of the data is now so apparent that at least four stations at Belmore will remain permanently. All current stations will remain at Belmore for at least another 6 months to see the results of a flood, and gain more information on hot spots, then some of the monitors may be moved to Kinchela Creek and other places. With work proposed on the Kinchela Creek levees it is now necessary to begin monitoring in the upper Kinchela Creek area, and a new station has been established there, with another one at Clybucca Creek..

Data from the current 10 water quality stations in the system provide 5 parameters at 15 minute

intervals. The data is also linked to councils flood warning system and integrated with 17 rain gauges and 14 river height gauges in the Macleay catchment to provide a very comprehensive coverage of the catchment.

Kempsey Shire Council, with the support of Greenspan Technical Services and the local community has developed a very useful water quality monitoring and environmental control system which should allow measures to reduce the impacts of flood mitigation and acid sulphate soils upon fish species and the environment and will assist future environmental study.

At a recent seminar on ASS at Kempsey attended by Dr. Ian White, Professor of Water Resources at the Australian National University and Technical Consultant to ASSMAC, he praised the system as “adventurous and innovative” and of “world class”.

It is perhaps fitting that in the area where Acid Sulfate Soils were first identified in Australia, a significant step is being taken towards remediation and control methods for acid runoff.

This is a copy of a Paper prepared by Mike Dutton, on behalf of Kempsey Shire Council, for the Institute of Municipal Engineering Australia Award in 1999

APPENDIX A

Typical graphed results of water quality monitoring in Belmore River, upper and lower reaches.

