Salinity is one of Australia’s most costly environmental problems causing damage to roads, buildings, agricultural production, rivers and water supplies.

To tackle salinity, we need to know exactly where the salt lies in the landscape, how it moves, how quickly it is moving, and where it is most likely to cause damage in the future.

The Bureau of Rural Sciences (BRS), working with other scientists, has demonstrated that salt is localised and moves along well-defined underground pathways. Once this is understood, specific actions can be taken to treat the cause and the effect.

This Science for Decision Makers sets out a 5-step approach to tackling salinity:
- consult to specify management objectives
- map salt stores, identify at risk areas
- consult to identify management options
- work with community to develop and implement action plan
- monitor and review.

The Billabung catchment (southern New South Wales) case study shows that changes in land use over only 16,000 hectares could deliver half of the Upper Murrumbidgee’s salinity reduction target.

Combining data from airborne salinity mapping for selected areas with soil and landform data provides very cost effective information. In the Billabung catchment, development of options for managing farm level salinity across the catchment cost 60 cents per hectare.

Where salt is localised in the landscape, management interventions can be focused on those areas of real risk, and specific interventions can be tailored to individual situations. Therefore, the cost of effective salinity management will be an order of magnitude less than some earlier predictions.
THE PROBLEM

Salinity affects both rural and urban areas. The National Land and Water Resources Audit (2001) estimated that, across Australia, some 5.7 million hectares of farmland could be affected by salinity and rising watertables. In the Murray-Darling Basin alone, salinity costs around $250 million a year in lost farm production. Off-farm costs are even greater: salt contaminates the water supplies of cities and country towns, and breaks up roads and buildings, costing tens of millions of dollars each year.

THE CAUSES

Salt occurs naturally in the landscape. It has been deposited over millions of years by wind and rain. Clearing of native vegetation for agriculture has allowed more rainfall to infiltrate deeply into the ground. In some cases, this has caused the water tables to rise closer to the surface bringing salt with them. In other cases, rainfall leaches the stored salt to other areas via underground conduits.

THE NATIONAL ACTION PLAN FOR SALINITY AND WATER QUALITY

The National Action Plan is a $700 million Commonwealth initiative, matched by the States and Territories, to enable concerted action by communities to tackle salinity. If this action is to be effective, it is essential to know where the salt lies in the landscape, the conduits through which it moves, the rate of delivery and how this could be changed through land management or engineering solutions.

THE BILLABUNG CREEK CATCHMENT

The Billabung Creek catchment was chosen as a case study to demonstrate how new methods for salinity mapping and management could be applied in the National Action Plan. The catchment lies between Cootamundra and Junee in southern New South Wales. It covers some 93,000 hectares or 3% of the Upper Murrumbidgee Catchment (Figure 1). The landscape comprises highlands in the east, reaching 760m above sea level; undulating hills in the west; and a broad central plain. Land use is mixed pasture and cropping on the hills and plain, and mixed woodland and pasture in the highlands.

FIGURE 1
LOCATION OF THE BILLABUNG CATCHMENT WITHIN THE UPPER MURRUMBIDGEE, NEW SOUTH WALES
Visible salt outbreaks cover less than 0.5% of the area, occurring around springs in the highlands and in some low-lying areas on the plain. Salinity in streams in the catchment varies from fresh (less than 100 µS/cm) to too salty for most irrigation purposes (more than 6,500 µS/cm) (Box 1). Billabung Creek typically only flows in winter, carrying about 5,000 tonnes of salt each year to the Murrumbidgee River.

However, as much as 30,000 tonnes each year is exported from the catchment by underground water flow. By comparison, the Murrumbidgee at Wagga Wagga carries, on average, 400,000 tonnes of salt each year. The target for salinity reduction in the Murrumbidgee at Wagga Wagga, set by the New South Wales Government, is 30,000 tonnes per year.

**THE 5-STEP PROCESS TO MAPPING AND MANAGING SALINITY**

A 5-step process was developed in the Billabung catchment:

1. Consult with the community to specify salinity management objectives
2. Map salt stores and identify areas likely to be at risk from salinity
3. Consult with land users and professional agencies to identify feasible management options
4. Work with the community to develop and implement an action plan

### BOX 1

**MEASURING SALINITY**

Salinity in water is measured most conveniently by its electrical conductivity (EC); the greater the salt content, the higher the electrical conductivity. For stream and potable water, the unit of measurement is micro Siemens/cm (µS/cm), commonly referred to as ECs. The World Health Organisation sets the optimum drinking water limit at 830 µS/cm, with a maximum tolerance of 2,500 µS/cm.

Other examples are:

<table>
<thead>
<tr>
<th>Stock water for:</th>
<th>Limits</th>
<th>Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horses</td>
<td>7,800</td>
<td>11,600</td>
</tr>
<tr>
<td>Cattle</td>
<td>11,400</td>
<td>16,600</td>
</tr>
<tr>
<td>Sheep</td>
<td>15,700</td>
<td>23,000</td>
</tr>
</tbody>
</table>

**Other comparisons:**

- Seawater: 40–50,000
- Light beer: 1,100

### APPLICATION OF THE SALINITY MAPPING PROCESS IN THE BILLABUNG CREEK CATCHMENT

**Step 1**

Establish salinity management objectives

BRS worked with regional staff from the NSW Department of Infrastructure, Planning and Natural Resources and consulted local landholders to establish salinity management objectives for this project. The primary objective was to reduce the amount of salt entering the Murrumbidgee from the Billabung catchment.
Airborne electromagnetics and airborne radiometrics were used to map salinity in the Billabung Creek catchment. These are often used in conjunction with airborne magnetics data and digital terrain models.

**Airborne electromagnetics (AEM)**
Underground salt can be mapped in three dimensions by measuring the conductivity of the ground—which is directly related to its salt content. Salt water is more conductive than fresh water or solid rock, and therefore can be identified. To map large areas quickly, specially equipped aircraft are used.

An on-board generator sends pulses of electric current through the aircraft’s transmitter loop. These create an electro-magnetic field that penetrates the ground, and induce a secondary current in conductive materials that is detected by a receiver towed behind the aircraft.

The signals are translated into a three-dimensional map that is calibrated by measurements from bores. The calibration bores also provide an opportunity to measure the hydraulic conductivity (the ease of transmission of groundwater) of the various sub-surface layers. Figure 3 shows the conductivity pattern 10–15 metres below the ground surface. Red indicates conductive materials (and therefore salt), and blue indicates resistive materials—bedrock and fresh water.

**Airborne radiometrics**
Measurement of the natural gamma radiation emitted by uranium, thorium and potassium in the surface soil provides detailed spatial information about soil composition and thickness that is then checked by fieldwork. Gamma radiometrics was used to map the uplands in the Billabung catchment. In Figure 4 the light blue areas in the image coincide with areas of thick, clay soils from which salt is leached to the streams.

**Digital terrain models**
Three-dimensional terrain maps produced from the aircraft’s altimeter are combined with airborne geophysical and bore information to predict salt discharge sites and enable calculation of water and salt movements.

**Airborne magnetics**
This technique has been used in other catchments studied by BRS to help map salinity. It measures the Earth’s natural magnetism, revealing subsurface structures such as rock barriers that may intercept or divert groundwater and prior stream channels that act as conduits.
The regolith is the blanket of materials (soils, sediments and weathered rocks) between the surface of the earth and unweathered bedrock.

Information about the location of salt stores, landforms, regolith and soil types, was combined with an estimate of deep drainage (Box 3) in a hydrogeological model to examine water and salt flows through the landscape under different land use scenarios. This provided a picture of areas at risk, and identified areas where reducing the amount of water going to deep drainage would have the biggest impact on salinity.

Rising water tables are not likely to be a serious issue for the lowlands region, as the catchment appears to be well drained. However, salt will be leached from the extensive salt stores in the lowland clay soils into the underground flow system, and then to the Murrumbidgee River.

The regolith is the blanket of materials (soils, sediments and weathered rocks) between the surface of the earth and unweathered bedrock.
Step 3
Identify management options

In consultation with local land and water managers, management domains were defined for the Billabung catchment, based upon salinity management objectives.

If the goal is to reduce salt exports to the Murrumbidgee, then the lowland salt stores areas should be the target for recharge reduction. These areas make up only 10% of the catchment, but contribute almost one quarter of its salt load. This intervention would have the most rapid impact on salt exports.

If the main objective was to reduce salt outbreaks at the soil surface, then the shallow upland salt stores should be the target for reduction of recharge and runoff. Reduction of recharge to the highland salt stores will have an immediate effect on local salt outbreaks, as well as on the quality of stream waters. These areas are responsible for nearly a third of total salt exports, although they represent only 6% of the catchment area.

Conversion of critical areas from annual crops and pastures to perennial forage and pastures in the plains, as well as some targeted afforestation in the highlands, will significantly reduce recharge and subsequent salt export from the catchment. These priority areas for intervention (16,000 hectares) total 17% of the Billabung catchment.

Reducing recharge over these areas through land use change could achieve a 50% reduction in salt export to the Murrumbidgee, with limited impact on agricultural profitability.

Step 4
Develop and implement a plan of action

This step must involve all landholders and managers in the area. Local Landcare groups, state agencies, local governments and individuals all have a vested interest in ensuring salinity is dealt with in the most cost efficient and effective way. This should occur through local negotiation and agreed action.

Step 5
Monitor and review effectiveness

Assessing the effectiveness of the action will require monitoring of groundwater levels at selected sites, changes in the areal extent of salt outbreaks, and in the conductivity of Billabung Creek and Murrumbidgee waters up and downstream of its confluence with the Billabung.

Monitoring over a period of 5–10 years will be needed to ascertain that observed changes are due to the impact of the new management rather than climatic variability. Tracking changes over this time will establish whether further modifications to land use are needed to meet salinity management objectives.

---

**Box 3: Estimation of Deep Drainage**

The amount of water draining to the groundwater may be estimated from measured rainfall by subtracting:

1. water that runs off over the surface (runoff) and 2. water soaking into the soil and subsequently used by crops or pastures (crop water use); and adding water that runs onto low-lying ground from land above (runon):

\[
\text{Drainage} = \text{Rainfall} + \text{Runon} - \text{Runoff} + \text{Crop water use}
\]

Crop water use may be estimated in a variety of ways, depending on the data available. Evaporation pan measurements from nearby weather stations were adjusted for wind and humidity to give reference crop evapotranspiration \( (E_o) \) for the Billabung catchment, following Doorenbos and Pruitt (1992).

Potential crop water use by each different crop \( (E_{crop}) \) was estimated by multiplying \( E_o \) by the appropriate crop coefficients \( (k_c) \) according to the stage of growth, with calculations performed for ten-day periods:

\[
E_o \times k_c = E_{crop}
\]

It was assumed that the soil was at field capacity in spring, and that crops used water at the potential rate up to half of the soil’s available water capacity \( (AWC) \) and the remaining available water at half the potential rate. It was assumed that the soils of the lowlands and the thick clay soils of the highlands had an \( AWC \) of 220mm, and that thin soils had only half this \( AWC \).

When the soil is re-wetted, the available water capacity is first replenished; any further water soaking into the soil appears as deep drainage.
This study, and much larger surveys in the Mid-Broken (Victoria), Billabong Creek (NSW) and the Lower Balonne (Queensland), demonstrate that salt is localised in the landscape. Extensive areas are essentially free of salt, and even large salt stores may not present a salinity risk if the salt is not going to be mobilised. This means that management intervention can be focused on those areas that present real risk, and specific interventions can be tailored to individual situations. Therefore, the cost of effective management of salinity will be an order of magnitude less than some earlier predictions.

In the case of Billabung Creek, land use change over a small area should achieve a substantial reduction of salt exports and deliver up to half the salt reduction target for the Upper Murrumbidgee Catchment.

**CONCLUSIONS**

Airborne geophysical survey is invaluable in providing the basic data needed for managing salinity. Used in combination with other data, they can provide cost-effective information about the location of salt, the likelihood of its mobilisation and options for salinity management.

**COST**

Depending on the size of the area flown, the current commercial costs of airborne survey range from $50-80 per line kilometre for AEM, and $8-12 per line kilometre for combined magnetics and radiometrics. This translates to a cost of $3-5 per hectare.

The detailed information collected through airborne mapping for key areas can be extended to the whole catchment using other information. For the Billabung Creek catchment, projection of the AEM information from a key area of 9,000 hectares to the whole catchment, using air photo interpretation of landforms, field reconnaissance and the use of the cheaper airborne radiometrics over the highlands, reduced the cost per hectare to about 60 cents, including staff time. The results provide information suitable for developing land use options at the farm (1:25,000) scale.

**IMPLICATIONS FOR POLICY AND MANAGEMENT**

Airborne geophysics provide a unique insight into the location and quantity of salt in the landscape, and the conduits along which it moves. Survey of key areas can be extended to whole catchments using existing data, which substantially reduces the cost of acquiring the information needed to develop salinity management options. This requires careful choice of the key areas for airborne survey.

**CONTACT**

FOR MORE INFORMATION CONTACT:

Peter Baker, Program Leader
Integrated Water Sciences
Bureau of Rural Sciences

EMAIL Peter.Baker@brs.gov.au
PHONE (02) 6272 5609
FURTHER READING

Braaten R, P Baker and DL Dent 2003
Steps to Solving Salinity: a systems
approach to salinity, Billabung Creek,
NSW. BRS Report, Canberra

Dent DL, KC Lawrie and TJ Munday
1999 Running down the salt in
Australia, 1 A multi-disciplinary
approach. The Land (Ghent) 3, 3,
179–198

Doorenbos J and WO Pruitt 1992
Crop water requirements. Irrigation
and Drainage Paper 24, Food and
Agriculture Organisation, Rome

Lawrie KC, TJ Munday, DL Dent,
DL Gibson, RC Brodie, J Wilford,
NS Reilly, RA Chan and P Baker
2000 A geological systems approach
to understanding the processes
involved in land and water
salinisation. AGSO Research
Newsletter May 2000, Canberra.

National Land and Water Resources
Audit 2001 Australian dryland
salinity assessment 2000. National
Land and Water Resources Audit,
Canberra

Wilford J R, DL Dent, R Braaten
and T Dowling 2001 Running
down the salt in Australia 2,
smart interpretation of airborne
radiometrics and digital elevation
models. The Land (Ghent) 5, 2,
79–100.