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Technical Manual for Assessing Hotspots in Channel and Piped Irrigation Systems

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Contents

List of figures

List of tables

EXECUTIVE SUMMARY

This *Technical Manual for Assessing Hotspots in Channel and Piped Irrigation Systems* has been developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) as a key component of the Irrigation Infrastructure Hotspots Assessment project (Hotspots project) under the 'Sustainable Rural Water Use and Infrastructure' element of Australian Government 'Water for the Future' program.

The objective of the Hotspots project is to identify areas in an irrigation supply system where localised significant water losses are occurring, through evaporation, seepage, leakage and operational components.

This technical manual follows on from a series of workshops that were organised by the CSIRO, in collaboration with the International Centre of Water for Food Security at Charles Sturt University. A separate paper entitled *Project Report: Development of the Technical Manual for Assessing Hotspots in Channel and Piped Irrigation Systems* details this process.

The technical manual is designed for irrigation water providers and consultants, to help them evaluate water losses and gains in open-channel irrigation delivery systems, as well as in piped irrigation delivery systems.

This technical manual:

- is modular in nature;
- details the sequence of technologies required for assessing hotspots, in both data-rich and data-poor settings;
- details how the recommended technology should be used (calibration and associated Australian or International Standard) and the subsequent accuracy of those technologies; and,
- provides a step-by-step standardised procedure for using the given technologies.

The technical manual can be used to:

- identify least-cost system analysis techniques (from diagnostic to detailed measurements) for identifying and quantifying sources of water loss and potential savings; and,
- spatially prioritise hotspot assessments at subsystem level that have been done using different techniques, and identifying what further database and analysis need to be done.

This manual includes many of the proven methods trialled in Australia and overseas. Water balances can be ‘top-down’ or ‘bottom-up’, depending on the setting. The ‘top-down’ water balance starts at the irrigation system level and disaggregates different components of flows to a lower level of detail only if necessitated by the purpose of the project. The ‘bottom-up’ water balance starts with the description of the lower level processes (for example crop water balance or channel seepage) and scales up or aggregates these processes to the irrigation system level to develop a system water balance.

The technical manual can be used to evaluate water losses and gains for open-channel irrigation systems and piped irrigation systems, in both data-rich and data-poor settings. A whole-of-irrigation-system approach has been taken to provide insights into possible real water savings, including distinguishing between apparent and real losses and gains.

1. ACRONYMS AND ABBREVIATIONS

AEM	airborne electromagnetic
IAL (ANCID)	Irrigation Australia Limited[1] (Australian National Committee on Irrigation and Drainage)
ANN	artificial neural network
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEM	digital elevation model
DEWHA	Australian Government Department of the Environment, Water, Heritage and the Arts
EM	electromagnetic
ET	evapotranspiration
ET_o	reference crop evapotranspiration
FAO	Food and Agriculture Organisation
GIS	geographic information system
GPR	ground-penetrating radar
GPS	global positioning system
GSM	global system for mobile communications
GW	groundwater
IWA	International Water Association
K_c	crop coefficient
M&E	monitoring and evaluation
ML	megalitre
PVC	polyvinyl chloride
SLURP	simple lumped reservoir parametric model
SWAP	soil-water-atmosphere-plant model
TCC	total channel control

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[1] Formerly ANCID

INTRODUCTION

1.1 Background

The *Technical Manual for Assessing Hotspots in Channel and Piped Systems* was written for irrigation water providers and consultants, to help them to evaluate water losses and gains in open channel and piped irrigation delivery systems. The steps in this manual can be used in systems for which there are significant data available, as well as systems that have relatively little data.

Irrigation water providers maintain complex water distribution networks in Australia. The irrigation infrastructure consists of more than $6 billon of assets in 73 supply systems, managed by more than 31 irrigation water providers who service more than 46,000 irrigators and 270 towns. The total service area of these irrigation water providers is 3.3 million hectares. The system delivers 9.5 million ML of allocated water through approximately 58,300 supply points (ABS 2005).

System conveyance losses occur when water is transported from the source to the farm gate. The overall surface water conveyance efficiency of different irrigation areas in Australia ranges from 67 to 90 per cent, depending on the type and age of channel or piped infrastructure, irrigation methods, irrigation scheduling, and the management practices of irrigators (Khan et al. 2008, Smith 2007).

In this technical manual, locations where relatively intense water loss occurs (for example via seepage or, leakage, evaporation and operational processes) are referred to as 'hotspots'. A hotspot assessment is a process to identify and quantify losses through evaporation, seepage, leakage and system operations. One of the first, and most important, steps in a hotspot assessment is calculating the water balance. This is the sum total of water that flows into, and water that is lost from, the irrigation system. In an ideal scenario, the water balance should be zero, that is, inflows and outflows (including allowable losses) are equal.

The standardised approach presented in this technical manual can be used to spatially evaluate water losses within irrigation districts. The technical manual can be used to:

- Identify least-cost system analysis techniques (from diagnostic to detailed measurements) for identifying and quantifying the sources of water losses and potential savings; and,
- spatially prioritise hotspot assessments at subsystem level that have been done using different techniques, and identifying what further database and analysis need to be done.

Water balances can be 'top-down' or 'bottom-up', depending on the setting. The 'top-down' water balance starts at the irrigation system level and disaggregates different components of flows to a lower level of detail only if necessitated by the purpose of the project. The ‘bottom-up’ water balance starts with the description of the lower level processes (for example crop water balance or channel seepage) and scales up or aggregates these processes to the irrigation system level to develop a system water balance.

The technical manual can be used to evaluate conveyance water losses and gains within irrigation districts and to inform strategies for improving water productivity with minimal environmental impact. This technical manual builds on the previous investigations in seepage detection (for example ANCID 2003) and the experience of irrigation water providers.

This technical manual is designed for open-channel irrigation systems, as well as for piped irrigation systems, in data-rich or data-poor settings. A whole-of-irrigation-system approach is used to provide insights into possible real water savings by tracking water pathways, including distinguishing between apparent and real losses and gains. This technical manual includes many of the proven methods trialled both in Australia and overseas and provides a step-by-step, standardised process for assessing hotspots.

1.2 Overview of a hotspot assessment

Figure 1 describes the overall concept of the strategic hotspot assessment, which consists of a water balance, detailed loss assessment, database development, and monitoring and evaluation. This schematic also underpins a more specific way of viewing the steps involved and their interactions in an irrigation system.

This manual focuses on the water balance and detailed loss assessment components. Practitioners intending to undertake a hotspot assessment independent of this process should consider all of these components.

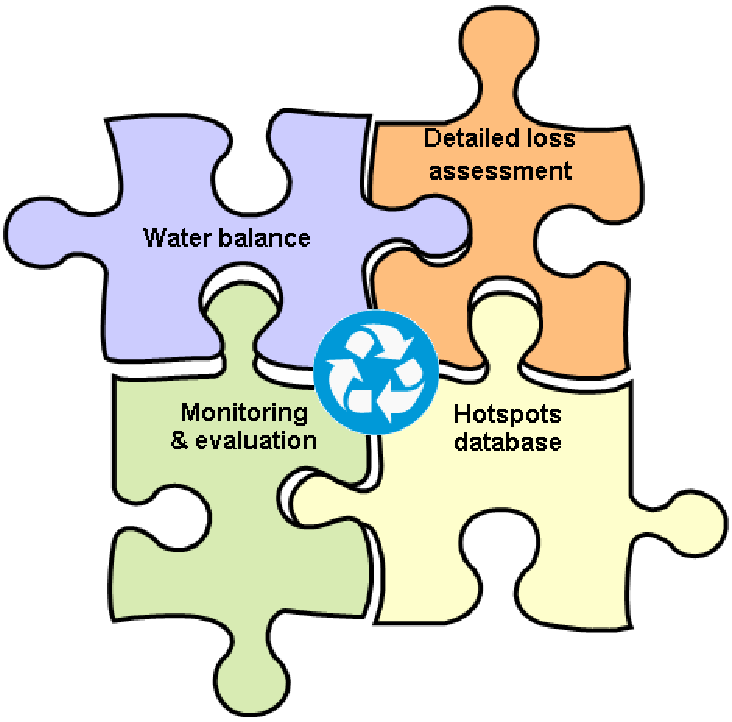

Figure 1: Paradigm of the strategic hotspot assessment

Figure 2 (over) describes the decision support framework of the hotspot assessment process, based on the data availability and magnitude of water losses.

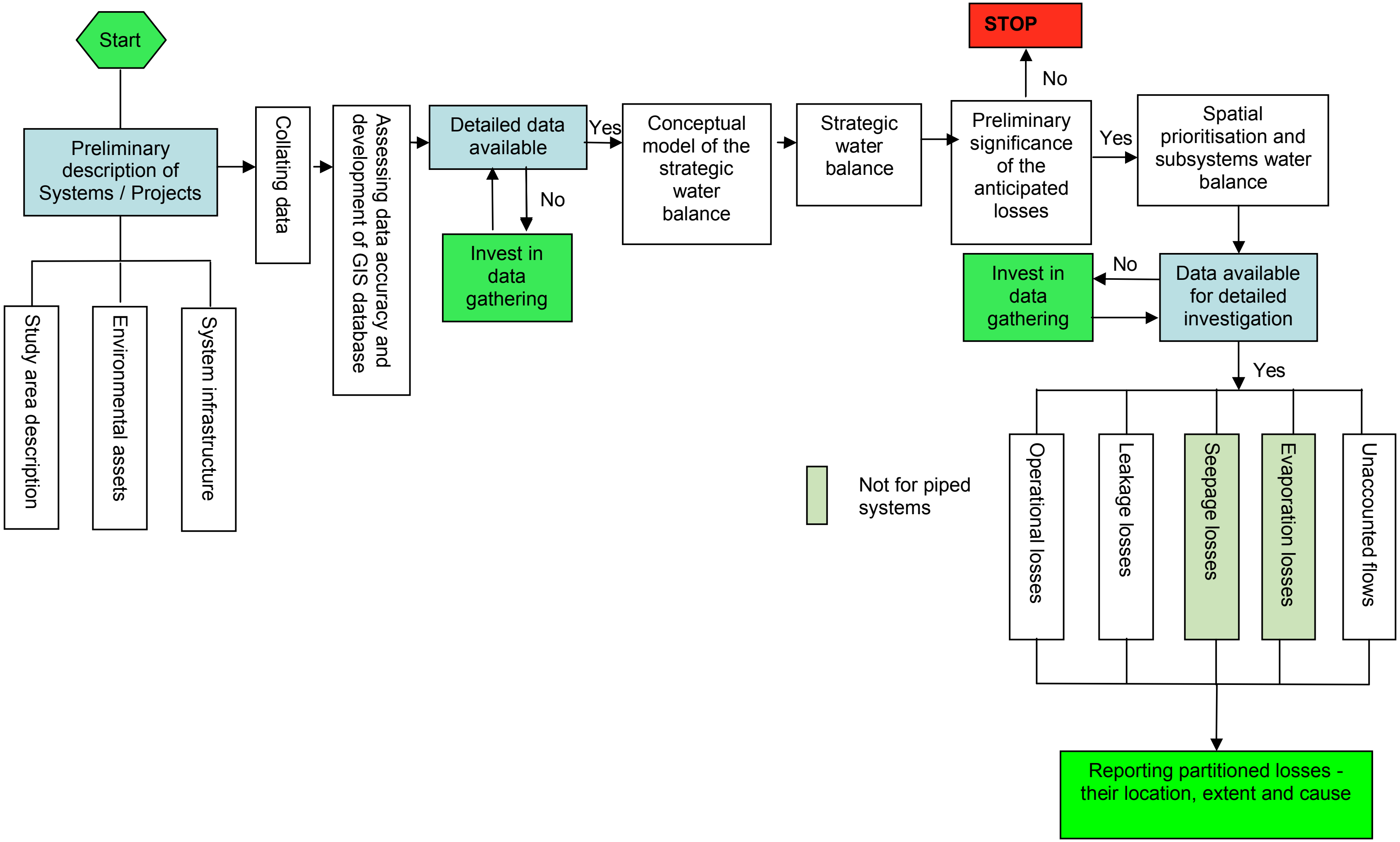

Figure 2: Hotspots assessment framework in irrigation systems

1.3 Structure of this manual

This technical manual is designed to be a practical document to help irrigation water providers and consultants assess irrigation hotspots in their systems. Therefore, the technical manual is presented step-by-step, with separate sections for open-channel and piped irrigation systems, as well as information common to both.

The technical manual is organised into the following sections:

- Section 1: Introduction
- Section 2: Preliminary description of systems and projects
- Section 3: Open-channel irrigation systems
- Section 4: Piped irrigation systems
- Section 5: Reporting partitioned water losses – their location, extent and causes.

The appendices provide detailed information on methods of measuring water losses.

2. PRELIMINARY DESCRIPTION OF SYSTEMS AND PROJECTS

This section details information requirements with regard to the characteristics of the study area and irrigation system being investigated.

2.1 Study area description

Describe briefly the irrigation area, including the following key points:

- the location of the irrigation water provider in a catchment
- a description of the district's operational framework
- a schematic diagram of where the water is and where it is flowing
- a narrative description of the strategic water balance and any anticipated hotspots
- the anecdotal evidence of channel and or pipe lengths and the areas where losses occur
- economic information about the district's water use efficiency

Spatial representation of the irrigation area, the environmental assets and infrastructure should be produced in ArcGIS format or similar.

2.2 Environmental assets

Describe the environmental assets in and around the hotspots region. The description should include the following items:

- the type of environmental asset
- a description of its significance
- how the asset is connected with the losses from the conveyance system
- likely environmental threats
- environmental watering obligations/requirements

2.3 Irrigation system infrastructure

Provide a detailed description of the irrigation system infrastructure for the study area, such as:

- bridge
- flume
- siphon
- culvert
- dethridge outlet
- metered outlet
- pump station
- unmetered outlet
- bridge regulator
- culvert regulator

- offtake
- regulator
- transition sump
- utility
- town water utility
- air valve
- scour valve
- walkway
- escape
- private pump
- radio tower
- monitor device
- channels and/or pipes

2.4 Irrigation flow measurement infrastructure (type, location)

Provide information on the location and type of the irrigation flow measurement devices in the hotspots areas. Use Table 1 as a template for this description.

Table 1: Template for flow measurement structures in an irrigation system (top-down assessment)

Type	Accuracy	Calibration history	Location	
			X	Y
Private pump Radio tower Monitor device Flume Siphon Culvert Dethridge outlet Metered outlet Pump station Unmetered outlet Bridge regulator Culvert regulator Offtake Regulator				

In locations where irrigation flow measurement infrastructure is incomplete, or where accurate flow measurements are not available, auxiliary data on crop areas and water use are needed. This should be provided in the format provided in Table 2.

It is important to note that it is not necessary to complete Table 2 when there are adequate flow measurements available.

Table 2: Template for detailed data on land use, actual and theoretical crop water use in an irrigated area (bottom-up assessment)

Land use	**Area (ha)**	**Recorded crop water use (ML)**	**Theoretical crop water requirements using crop coefficient (ML)**
Rice Lucerne Perennial pasture Summer crop Barley Wheat Oats Canola Annual pasture Grapes Citrus Stone fruit …………. ………….. …………..			
Totals			

Determine the theoretical crop water use using the crop coefficient (K_c) and the reference crop evapotranspiration (ET_o) using the FAO 56 Penman-Monteith method shown in Table 3 (over). This theoretical crop water use will be used to compare the inflows and outflows with the likely water use in situations where the water flow data are less than 20 per cent accurate.

The FAO 56 Penman-Monteith is the preferred method, however if evaporation and seepage are major components for the channel reach being considered, the isotope mass balance method can be used for seepage component of the water balance.

Table 3: Accuracy of on-farm methods for quantifying water balance components

Technique	Scale			Qualitative	Quantitative	Applicability	Accuracy	References
	Local (Micro) (<1 km)	Medium (1 km to tens of km)	Macro (tens of km to whole system)					
Penman-Monteith model (FAO-56)	√	√			Local quantitative	Most reliable method for estimating crop-water requirements	+1%	Kassam and Smith (2001)
Isotopic Mass Balance	√				Local quantitative	Applicable to irrigation channels if evaporation & seepage are major components for the channel reach	Deuterium ^{2}H Error is about 11% (11 parts per mL), which results in an error of 10–20% for seepage. The error is reasonable for <20 mm/day but overestimated if rates are >50 mm/day	Leaney and Christen (2000)
Hydrological models		√	√		Bulk or distributed Quantitative	Reasonably accurate when properly calibrated	SWAP model: 80% on local scale and 90% on medium scale compared with FAO-56	Kite and Droogers (2000)
							SLURP model: 76% on local scale and 86% on medium scale compared with FAO-56	
							WetSpass* model: +10% on long-term (>20 years) and +20% on short-term (up to 5 years) water balance	Pokojska (2004)

2.5 Additional information

Provide a brief description of further information that could be drawn upon in the hotspots assessment, including:

- existing data sets
- local operator and landholder knowledge
- field observations
- available soils, geology and land use digital maps
- available imagery, Digital Elevation Model (DEM) and other data, if any
- synthesis of significance of the irrigation area management opportunity

3. OPEN-CHANNEL IRRIGATION SUPPLY SYSTEMS

This section describes how to assess open-channel irrigation supply systems, including how to calculate a strategic water balance in data-rich and data-poor settings.

3.1 Collating data

Collate dispersed data from multiple organisations and build a framework that accounts for all water within the subsystem. The data listed below are required to complete a strategic water balance at the irrigation system level.

- Surface water components
    - River diversions
    - Total length and width of existing supply channels in the system
    - Supply channel losses if available
        - Evaporation
        - Seepage/Leakages
        - Operational
    - Actual volume delivered to farms
    - Entitlements and allocations

- Groundwater data where such data have been collected in the past
    - Piezometric data — watertable behaviour
    - Pumping rates
    - Recharge — discharge
    - Leakage between aquifers
    - Aquifer water quality

- Climatic data
    - Pan or measures of evaporation
    - Rainfall

- Crop water demand and use (in data poor environments only).

These data need to be collated, where possible, on a yearly or more frequent basis for a 10-year sequence that includes dry, wet and average water allocation years.

3.2 Assessing data accuracy and availability

The decision on how to proceed with the strategic water balance depends upon the range, size, accuracy and frequency of the data available. The strategic water balance can be carried out either in a data-rich (top-down) or data-poor (bottom-up) setting.

The data reliability is important for setting objectives. The data from various sources may be erroneous, creating misleading information. The accuracy of the data is highly important for the hotspot assessment, therefore it is important to check the accuracy using ground truthing, interviews/growers' experience. This is the first decision point for developing sufficient confidence to proceed to the strategic water balance. When the accuracy and adequacy of data is identified, the strategic water balance is carried out as the first-cut analysis of the system for initial understanding of water losses.

Meters provide the most important source of information because they record water flow and provide data that determine water loss. Historic data on meter testing, calibration and replacement programs is an important source of information for assessing the accuracy of meters. Irrigation water providers not calibrating water meters regularly may be supplying more water than what is actually authorised, and therefore this water in the distribution system would otherwise be considered a loss. If the accuracy of the meters is sufficient (90 per cent accurate in the field) then at this stage the project could proceed with a top-down assessment, otherwise a bottom-up approach should be applied.

3.3 Assessing at the system level

One of the first steps in a hotspot assessment is to calculate the strategic water balance — the sum total of inflows and outflows in the irrigation system.

Strategic water balances can be ‘top-down’ or ‘bottom-up’, depending on the setting. The ‘top-down’ strategic water balance starts at the irrigation system level and disaggregates different components of flows to a lower level of detail only if necessitated by the purpose of the project. The ‘bottom-up’ strategic water balance starts with the description of the lower level processes (for example crop water balance or channel seepage) and scales up or aggregates these processes to the irrigation system level to develop a system water balance.

This technical manual proposes a top-down strategic water balance approach as a first preference to identify the potential water savings at the system level. The objectives of a top-down strategic water balance are to:

- describe the major features of the hydrologic system relevant to potential water savings, for each irrigation district;
- quantify potential water savings using a whole-of-the-irrigation-system approach, in a least-cost manner; and,
- identify information gaps that need to be filled to help irrigation water providers to plan and make decisions about modernisation.

The top-down strategic water balance considers the difference between water inflow and outflow to identify and quantify the unaccounted water. The top-down water framework considers the quality of data available at bulk off-take and on-farm metering, and shows ways of identifying the exact location/reason for losses. It builds on existing methods and applies to open-channel irrigation systems.

Where a top-down strategic water balance is not possible, a bottom-up strategic water balance should be undertaken. The bottom-up strategic water balance involves quantifying individual water balance components at the smallest known scale and aggregating as appropriate.

3.4 Conceptual model of the strategic water balance

A standard, top-down strategic water balance approach in irrigation systems considers the loss of water during conveyance from the source to the farm gate. The objectives are to:

- describe the major ‘flows’ of the hydrologic system relevant to potential water savings;
- identify information gaps that need to be filled to help irrigation water providers plan and make decisions about modernisation; and
- calculate the water balance, quantifying the potential water savings using nested water balance at the ‘subsystem’ level, in a least-cost manner.

Table 4: Conceptual model of the water balance components in an irrigation system

Inflows to the system	* Water diverted from river * Water traded in from other districts * Groundwater abstraction * Rain on supply system	Authorised deliveries	* Water delivered to the growers * Water traded out to other districts * Water delivered to other authorised uses	* Metered and other diversions
		Water losses	Apparent losses	Escapes
				Over-flows
				Metering inaccuracies
				Chanel filling
				Channel emptying
				Theft
			Real losses	Seepage
				Leakage
				Evaporation

A strategic water balance at the irrigation system level aggregates dispersed data from multiple organisations to fill in the critical knowledge gaps, thereby helping to better understand all flows in the irrigation system.

The water balance of a supply system is calculated by the mass balance equation described as:

$$I = D + E_v + E_s + S + q + L \qquad (1)$$

Where:

I = inflows to the system (river, groundwater, traded in, rain on supply system)
D = authorised deliveries
E_v = evaporation
E_s = escapes
S = channel filling
q = seepage and leakage
L = unaccounted losses (overflows, metering inaccuracies, channel emptying, theft)

The accuracy of unaccounted loss estimates is subject to aggregate accuracy of the known flow terms.

A globally recognised hydrological cycle of an irrigation system identifies specific components of a water balance; these are listed in Table 5 (over). However, because it is not necessary to develop such a comprehensive water balance, the strategic water balance is recommended.

Table 5: Hydrological cycle at an irrigation system and basin level

Field	Irrigation service	Basin/sub-basin
Inflow		
• irrigation application • precipitation • subsurface contributions • surface seepage flows	• surface diversions • precipitation • subsurface sources • surface drainage	• precipitation • trans-basin diversions • groundwater inflow • river inflow into basin
Storage change		
• soil moisture change in active root zone	• soil moisture change • reservoir storage change • groundwater storage change	• soil moisture change • reservoir storage change • groundwater storage change
Process depletion		
• crop transpiration*	• crop transpiration	• crop transpiration • municipal and industrial uses • fisheries, forestry, and other non-crop depletion • dedicated environmental wetlands
Non-process depletion		
• evaporation from soil surface, including fallow lands • weed evapotranspiration • lateral or vertical flow to salt sinks • flow to sinks (saline groundwater, seas, oceans) • water rendered unusable due to degradation of quality	• evaporation from free water and soil surfaces, weeds, phreatophytes, and other non-crop plants • flow to sinks (saline groundwater, seas, oceans) • evaporation from ponds/playas • water rendered unusable due to degradation of quality	• evaporation from free water and soil surfaces, weeds, phreatophytes, and other non-crop plants • flow to sinks (saline groundwater, seas, oceans) • evaporation from ponds/playas • water rendered unusable due to degradation of quality • ET from natural vegetation
Outflow		
• deep percolation • seepage • surface runoff	• instream commitments such as environmental and fisheries • downstream commitments • for M&E use with irrigation service • uncommitted outflows	• instream commitments such as environmental and fisheries • downstream commitments • outflow commitments to maintain environment • uncommitted outflows

*Crop evapotranspiration may be considered process depletion when it is impractical to separate evaporation and transpiration components, or when separation of terms does not add to the analysis

Source: Molden 1997

3.4.1 Data-rich settings

The top-down strategic water balance can quantify conveyance/irrigation efficiency at various reaches of the water delivery system and thus identify the system hotspots. Table 6 represents the minimum potential datasets for data-rich settings. If any of these datasets are unavailable, the data environment is considered to be poor (Section 3.4.2).

Table 6: Minimum water balance components and their availability in data-rich settings

Data availability	
Component	**Yes/No**
Surface water (river diversions, water traded-in, drainage re-use)	√
Groundwater (pumping to supply system, on-farm use)	√
Landuse*	√
Soils	√
Climate	√
Channels / pipes	√
Location of diversion structures/gauges	√
Drainage/reuse	√
Irrigation area boundary	√
Groundwater levels	√
Geological formations	√
Native vegetation*	√
Farm boundary	√
Digital data (Digital Elevation Model, satellite imagery, geophysical, soils, geology, etc)	√

* Data sets like land use and native vegetation are relevant to validate the water use, if required

3.4.2 Data-poor settings

In data-poor settings, a combination of top-down and bottom-up strategic water balance could be used. As described in Section 2.4, in locations where irrigation flow measurements are incomplete, or where accurate flow measurements are not available, auxiliary data on crop areas and water use are needed (Table 2). This data should be used in combination with any of the datasets available in Table 6 for a combination top-down and bottom-up strategic water balance.

If top-down datasets are unavailable, a full bottom-up strategic water balance can be used to calculate water use efficiency. The bottom-up strategic water balance involves quantifying individual water balance components at the smallest known scale and aggregating.

3.5 Strategic water balance

Once a preliminary water balance is performed, the strategic water balance for data-rich settings should be calculated at the irrigation system and subsystem levels using the simple checklist shown in Table 7, for a period of ten years. Each step in the table refers to the relevant part of the strategic water balance. For data-poor settings, some of the surface flow components or groundwater data listed in the table may not be readily available; therefore, detailed flow estimates or shallow and deep groundwater estimates may be omitted. For data-poor settings, a partial water balance followed by a bottom-up strategic water balance can be followed.

Table 7: Strategic water balance model of open channel irrigation at the system and subsystem level

DESCRIPTION	**Year 1**		**Year 2**		**Year 3**		**…………**		**Year 10**		**Comments**
	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	
SUPPLY CHANNELS											
Diversions (river)											
Rain on supply											
Groundwater pumping											
Channel seepage											
Surface water deliveries											
Groundwater deliveries											
Channel filling											
Channel leakage											
Channel evaporation											
Drainage to river											
Escapes/unexplained											
RAINFALL											
Rainfall											
Rain on supply											
Rain on drains											
Rainfall runoff											
DRAINAGE											
Rain on drains											
Irrigation Runoff											
Escapes/unexplained											
Channel empty											
Rainfall runoff											
Evaporation drains											
Drainage in creeks											
Seepage in Drains											
SHALLOW GROUNDWATER											
Channel seepage											
Recharge											
Seepage from Drains											
Deep Leakage											
Lateral Outflow											
Capillary Rise											
Watertable Change											
DEEP GROUNDWATER											
Deep Leakage											
Lateral outflow											
Deep pumping											

The strategic water balance provides all information regarding water inflows, outflows and the quantitative assessment of the water losses (leakage, seepage, evaporation and operational) in open channel system. From the loss components of Table 7, the particular information on various losses are summarised in Table 8.

Table 8 Summary of the total losses of open channel irrigation at system and subsystem levels:

Type	Losses (ML)	Accuracy (%)
Leakage		
Seepage		
Evaporation		
Operational		

3.5.1 Preliminary significance of the anticipated losses

Once the strategic water balance has been used to identify potential losses, summarised in Table 8, the next step is to assess the economic significance of those potential losses.

A preliminary economic appraisal will include:

- the number of ML of water expected to be saved;
- the market value of water in the region; and,
- an estimate of infrastructure costs (in many situations, it may not be possible to estimate this if it is not clear where and how losses are occurring).

This will lead to a rough assessment of cost per ML of water saved and a recommendation as to which losses should be the subject of further detailed investigation.

A qualitative differentiation of apparent and real water losses and gains and an assessment of the likely environmental impact should be made by describing water pathways in the area. For example, some losses from the channels may recharge high-water quality aquifers that support consumptive and environmental uses. In these situations, there may be an apparent water loss from the channels but not from the system as a whole. Similarly, piping may eliminate seepage or even evaporation losses, but might affect recreational uses of water in-stream. Water savings are only net where they do not affect the productive or environmental gains from the water lost. They must deliver further productive or environmental gains from the saved water. Targeting these water savings can ensure the best value for money investments will be made during irrigation area modernisation.

3.6 Spatial prioritisation and sub-systems water balance

Initially, the strategic water balance is carried out at the irrigation system level. If significant losses are found at this level, further analysis at a subsystem level is needed to understand the effects of the losses on the environment. This analysis should be used to determine where in the irrigation system these significant losses are occurring. Subsequently, this ranks the local areas (subsystems) for further investigations according to the level of significant losses.

Science-based hotspots assessment requires a sub-system scale water balance. Developing a sub-system scale water balance requires a database that records all water entering and leaving the subsystem, to quantify the movement of water (water in and water out).

Once the spatial extent and quantity of channel losses has been determined, a subsystem-level water balance can be calculated. This water balance can then be used to determine the hydrologic and economic significance of seepage losses, and should be able to differentiate:

- water flowing into the conveyance subsystem
- water available at the farm gate after conveyance losses due to:
    - leakage
    - seepage
    - evaporation
    - escapes
    - operational loss (normally not real loss due to downstream uses) and possible gains
- unaccounted losses (subject to metering accuracy) during the conveyance
- crop water use along the canals.

The sub-system water balance should also inform consideration as to whether losses at the sub-system level should be the subject of further detailed investigation.

3.6.1 Collecting and collating data for detailed investigations

This element focuses on identifying and quantifying the components of the subsystem water balance (particularly operational, leakage/seepage, evaporation and unaccounted losses) of spatially prioritised areas using a range of technologies and methods.

The availability of data needs to be checked against the list given in Section 3.1. The data accuracy is checked against the methods used for data collection and calibration, record/performance testing of equipment and instruments, the operator knowledge, the purpose for which the data were collected, and the time period. Statistical and modelling tools can be used to validate the datasets.

3.7 Description of modules

The process of hotspot assessments comprises four assessment modules. The modular format makes it possible to choose the combination of assessment approaches best suited to a particular situation in the open channel irrigation at system and subsystem levels.

In an open channel system, seepage/leakage, evaporation, and operational components are the identified losses. The location and extent of these losses can be identified through qualitative and quantitative techniques.

(a) Qualitative approaches include: visual observations along the channel banks; remote sensing; and geophysical techniques.

(b) Quantitative approaches include: direct methods like inflow-outflow, seepage meters, and pondage tests; and indirect methods based on models.

Figure 3 shows qualitative and quantitative approaches for water loss assessments in open channels.

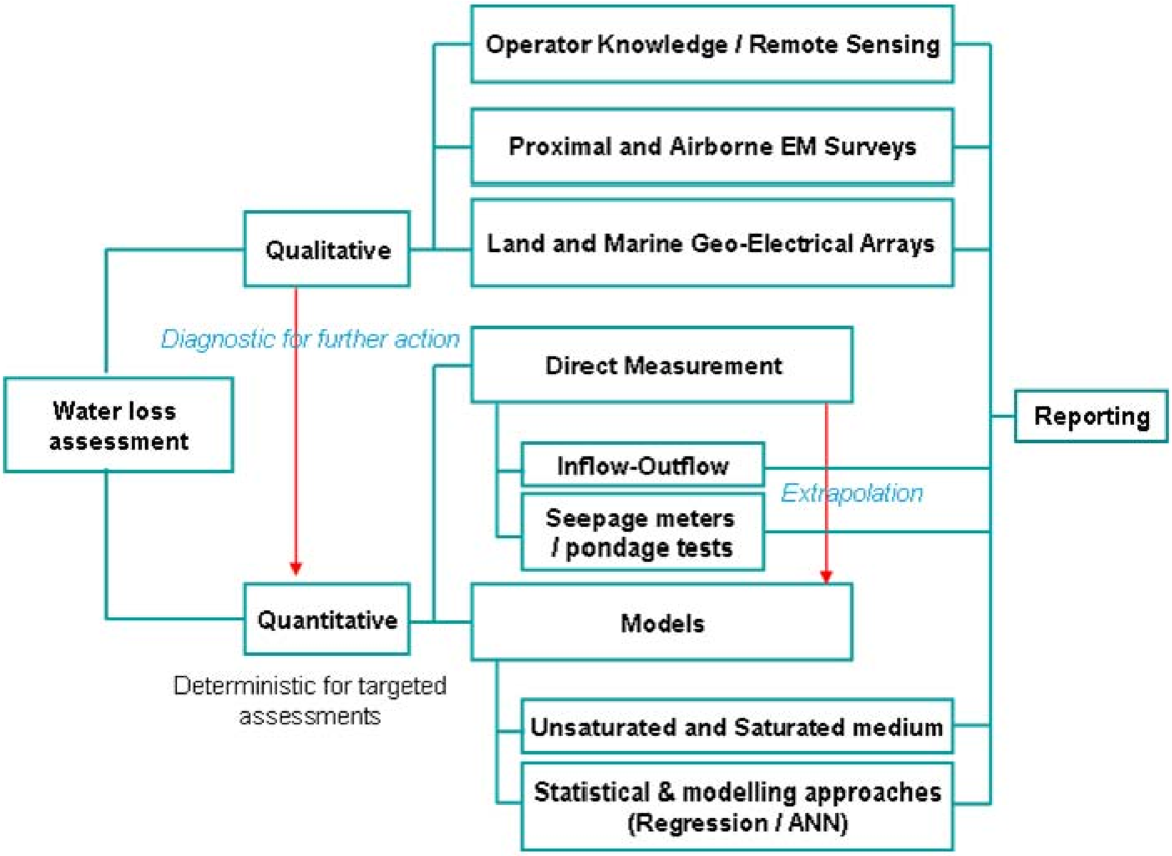

Figure 3: Framework for qualitative and quantitative assessment of channel losses

3.7.1 Seepage or leakage losses

Detailed investigation of seepage and/or leakage losses should use a combination of qualitative and quantitative techniques. Not all techniques will be necessary.

(a) Qualitative approaches include:

  - the ‘car stuck formula’ - observing health of vegetation on channel banks;
  - characterising subsurface aquifer and condition of groundwater resources in the vicinity of channels (see Appendix D);
  - remote sensing techniques, such as airborne thermal infrared imagery (see Appendix E);
  - electromagnetic surveys (see Appendices F and H); and
  - geo-electrical resistivity surveys (see Appendix G) for mapping seepage zones.

(b) Quantitative approaches include:

  - on-site seepage measurements using inflow-outflow method (see Appendix A), pondage tests (see Appendix B), and seepage meters (see Appendix C); and
  - at irrigation system level, using artificial neural network (ANN, Khan et al., 2004) and statistical modelling approaches.

3.7.2 Operational losses

Detailed investigation of operational losses should use a combination of qualitative and quantitative techniques. Not all techniques will be necessary.

(a) Qualitative approaches include:

  - assessing unmeasured supplies (using operator knowledge).

(b) Quantitative approaches include:

  - measuring escapes (using calibrated measuring rods and measuring discs, see Appendix A);
  - validating accuracy of metered deliveries (see Table 9); and
  - assessing channel emptying and overflows by flow measurements (see Appendix A) at off-take and at regular intervals (channel sections could be decided depending upon the real field situations) along the channels.

3.7.3 Evaporation losses

Detailed investigation of evaporation losses should use a combination of qualitative and quantitative techniques. Not all techniques will be necessary.

(a) Qualitative approaches include:

  - using a weather station/flux tower (evapotranspiration through channel or open-surface coefficients — not based on single evaporation factors); and
  - using remote sensing and satellite imagery (see Appendix E).

(b) Quantitative approaches include:

  - using class A pans (adopted by Australian Bureau of Meteorology).

3.7.4 Unaccounted flows

Detailed investigation of unaccounted flows should use approaches including:

- existing flow measurement wheels – calibration and checking the accuracy (using operator knowledge); and
- existing total channel control (TCC) systems (using operator knowledge)

The accuracies of these techniques are listed in Table 9. To fill the data gaps, losses need to be quantified so the strategic water balance can be completed.

Table 9: Accuracy of off-farm methods for quantifying water balance components (estimating channel losses)

Technique	Scale			Qualitative	Quantitative	Applicability	Standards/Calibration	Accuracy	References
	Local (<1 km)	Medium to large (1 km to tens of km)	Macro (tens of km to whole system)						
Electromagnetic induction (proximal and airborne)	√	√	√	Distributed qualitative		Most accurate & efficient method for quantifying seepage if calibrated; eg, w/ pondage test.	EM systems are calibrated for each soil type. Soil ECa is used to establish soil core sampling locations needed for calibration The geospatial EM data is calibrated against the observed sample data using geostatistical techniques.	EM34: Survey of the Donald Main Channel in the Wimmera–Mallee region showed correlation coefficient of 0.9 with the pondage test results	SKM (1998, 1999) Donald et al (2000)
						ECa data from map most likely seepage locations.	EM31 surveys along channels length shows that ECa is highly variable along their length and result into ECa zones . A suitable method for conducting surveys of channel zones is to carry EM31, while walking along a traverse, taking readings approx every 2m.	EM31: ECa to 6 m depth across a broad range of sites resulted in good correlations in spring ($R^2 = 0.66$) and autumn ($R^2 = 0.64$)	Kinal et al (2006) Corwin and Lesch (2005) McLeod and Shaw (2001) O'Leary et al (2006)
Geophysical resistivity (marine and land based)	√	√		Distributed qualitative		Slow - accuracy subject to ground truthing. Leak/seepage detection.	Equipment calibrated against different soil formations. Defined ranges of apparent resistivity values for each formation. The resistivity depends upon soil type, degree of saturation and the salinity level of both soil and water.	Electrical resistivity: A considerable degree of accuracy achieved when results compared with those of pondage tests and seepage meter number	Kraatz (1977) Loke (2000) ANCID (2003)
Remote sensing -thermal and hyperspectral		√	√	Distributed qualitative		Accuracy depends on terrain, vegetation types and spatial and	Data validated against on ground observations. Raw data needs corrections to remove noise effects. *Geometric Correction:* Involves the	Empirical direct methods: 10–20% errors at local scale	Seguin et al (1982) Steinmetz et al (1989)

Technique	Scale			Qualitative	Quantitative	Applicability	Standards/Calibration	Accuracy	References
	Local (<1 km)	Medium to large (1 km to tens of km)	Macro (tens of km to whole system)						
						temporal scales	extraction of aircraft roll, pitch, yaw and GPS data. *Atmospheric Correction:* Adequate atmospheric and radiometric corrections are applied to bring all scenes to a common radiometric datum. *Radiometric Correction:* Consistent image interpretation where radiance values for each pixel for each band represented in spectral radiance units (µW cm^{-2} sr^{-1} nm^{-1}). Sensor degradation & inter-platform differences when calibrating	Energy balance methods (SEBAL): 85% daily basis & 95% seasonal basis at field scale; 96% on watershed scale	Bastiaanssen et al (2005) Kite and Droogers (2000)
								Thermal infrared imagery: Approximately 30% interpretation accuracy	Nellis (1982)
								Scintillometer: 93% local scale and 80% on medium scale compared with FAO-56	Sedat et al (2008) Verstraeten et al (2005)
Inflow-outflow		√	√		Bulk quantitative	Fairly accurate over long sections, subject to accuracy of meters. Same device measuring inflows & outflows decreases the systematic errors.	Method is based on a water balance approach and enables direct measurement of losses. The flow measurement devices need to be calibrated against pre-calibrated flow regulating structures like flumes and weirs. Water loss estimates are best over long sections, without diversions; however, it is difficult to have an indication of spatial variation of losses within the section monitored.	Radial gates: 90% accuracy	Leigh et al (2003)
								TCC: 90% accuracy for water delivery	Murphy (2007)
								RiverCat: ±1% of measured velocity ±0.5 cm/s	SonTek (2008b)
								FlowTracker: ±1% of measured velocity ±0.25 cm/s	SonTek (2008a)
								Current meter:± 5 %	Herschy (1999)

Technique	Scale			Qualitative	Quantitative	Applicability	Standards/Calibration	Accuracy	References
	Local (<1 km)	Medium to large (1 km to tens of km)	Macro (tens of km to whole system)						
Pondage tests	√				Bulk quantitative	Most accurate method but at the local scale	Bank survey is essential and a minimum length of 50m is recommended. Clay barriers on both ends of the channel section are compacted and lined to prevent horizontal seepage. A rainfall gauge and evaporation pan is essential. Water levels are measured at multiple points within the channel.	The results from this method are generally used as the standard or benchmark. Other methods of seepage measurement are compared or calibrated against this datum.	Kraatz (1977) IAL (2008)
								Pondage tests give the most reliable results among the available methods for seepage assessment in open channels.	Templin et al (1997)
								Most accurate technique for determining seepage losses	ICID (1967) Smith (1973) Byrnes and Webster (1981) Hotes et al (1985)
Seepage meter	√				Local quantitative	Not reliable for absolute quantification of channel losses	Seepage meters are installed with the least possible disturbance of the bed material. This method requires a large number of tests to obtain a representative seepage rate over a given length of channel. Seepage meters can be used when channel is operational.	For a 366-metre-long channel section, 110 measurements were required for a 20% error in the overall seepage rate	Smith and Turner (1982)
								Idaho seepage meter underestimated by 26% and 34% of the respective ponding losses; the meter is unreliable at seepage rates above 400 mm/day	Byrnes and Webster (1981) IAL (2008)

Technique	Scale			Qualitative	Quantitative	Applicability	Standards/Calibration	Accuracy	References
	Local (<1 km)	Medium to large (1 km to tens of km)	Macro (tens of km to whole system)						
Statistical extrapolation or interpolation	√	√	√		Extrapolated or interpolated, distributed, quantitative	Not reliable for strongly varying soil textures	Statistical methods require the test results representative of the channel conditions over the total length	Confidence in extrapolation can be assessed by a number of statistical indicators: the correlation coefficient, standard error of estimate, and prediction interval	ANCID (2003)
ANN extrapolation	√	√	√		Distributed quantitative	The most realistic non-linear system estimates by training multiple parameters rather than simple mathematical formula	Model training and calibration should be carried out using different periods of data.	The generated output is assessed by the following performance measurements: mean square error (MSE), normalised mean square error (NMSE), mean absolute error and coefficient of correlation (R^2)	Khan et al (2005)

4. PIPED IRRIGATION SYSTEMS

4.1 Collating data

The standard procedure for collecting data from piped irrigation systems is to categorise the water balance components by their use. The following data are required to calculate a strategic water balance at the irrigation system level.

- River diversions
- Total length and diameter of pipes
- Piped system losses if available
    - Operational losses
    - Leakages
- Deliverable volume to the farms

4.2 Assessing data accuracy and availability

The decision on how to proceed with the strategic water balance depends upon the range, size, accuracy and frequency of the data available. The strategic water balance can be carried out either in a data-rich (top-down) or data-poor (bottom-up) setting.

The data reliability is important for setting objectives. The data from various sources may be erroneous, creating misleading information. The accuracy of the data is highly important for the hotspot assessment, therefore it is important to check the accuracy using ground truthing, interviews/growers' experience. This is the first decision point for developing sufficient confidence to proceed to the strategic water balance. When the accuracy and adequacy of data is identified, the strategic water balance is carried out as the first-cut analysis of the system for initial understanding of water losses.

Meters provide the most important source of information because they record water flow and provide data that determine water loss. Historic data on meter testing, calibration and replacement programs is an important source of information for assessing the accuracy of meters. Irrigation water providers not calibrating water meters regularly may be supplying more water than what is actually authorised, and therefore this water in the distribution system would otherwise be considered a loss. If the accuracy of the meters is sufficient (90 per cent accurate in the field) then at this stage the project could proceed with a top-down assessment, otherwise a bottom-up approach should be applied.

4.3 Assessing at the system level

One of the first steps in a hotspot assessment is to calculate the water balance — the sum total of inflows and outflows in the irrigation system.

Water balances can be 'top-down' or 'bottom-up', depending on the setting. The 'top-down' water balance starts at the irrigation system level and disaggregates different components of flows to a lower level of detail only if necessitated by the purpose of the project. The ‘bottom-up’ strategic water balance starts with the description of the lower level processes (for example crop water balance or pipe leakage) and scales up or aggregates these processes to the irrigation system level to develop a system water balance. Both approaches have their own advantages and limitations, depending on their intended purpose.

This technical manual proposes a top-down strategic water balance approach as a first preference to identify the potential water savings at the system level. The objectives of a top-down strategic water balance are to:

- describe the major features of the hydrologic system relevant to potential water savings, for each irrigation district;
- quantify potential water savings using a whole-of-the-irrigation-system approach, in a least-cost manner; and,
- identify information gaps that need to be filled to help irrigation water providers to plan and make decisions about modernisation.

The top-down water framework considers the quality of data available at bulk off-take and on-farm metering, and shows ways of identifying the exact location/reason for losses.

Where a top-down strategic water balance is not possible, a bottom-up strategic water balance should be undertaken. The bottom-up strategic water balance involves quantifying individual water balance components at the smallest known scale and aggregating as appropriate.

4.4 Strategic water balance at the system level

Piped systems may form one of the following two irrigation delivery system designs:

1. Direct pumping from the river, creeks or open channels, and delivered through piped systems for irrigation uses. In this system, water accounting will mainly deal with the piped systems.
2. Removing surface water from a control structure (for example dams and weirs), using open channels (earthen or concrete), and then delivering it through piped systems for irrigation. In this system, water accounting will be required separately for the open channel component and the piped system component.

In any of the designs mentioned above, a strategic water balance can be done using the top-down or bottom-up approaches. A strategic water balance of piped systems can provide a guide as to how much water is leaking out of the irrigation system (‘real’ losses), and how much water is lost due to ‘apparent’ or non-physical losses, such inaccurate measurement or unauthorised consumption. It does this based on the measurement or estimation of water produced, imported, exported, consumed or lost — overall, the calculation should balance.

The International Water Association (IWA), through its Water Loss Task Force, has produced an approach for water balance calculations for piped systems that is recognised internationally as best practice. The IWA approach includes definitions of its components and can be used to compare performance between water service providers. The IWA defines water loss as follows:

water loss = real losses + apparent losses

Real losses comprise the volumes lost through all types of leaks, bursts and overflows on mains, service reservoirs and service connections, up to the point of customer metering. Real losses can be severe (ranging from 44 per cent to 3 per cent). The volume lost depends largely on the characteristics of the pipe network and the leak detection and repair policy practised. There can be a vast difference in volume lost from leaks in the different parts of the distribution network.

The IWA approach can be found at www.iwahq.org/

Table 10 provides the various components of the strategic water balance in the piped irrigation systems.

Table 10: Strategic water balance model of piped irrigation at the system and subsystem level

DESCRIPTION	Year 1		Year 2		Year 3		…………		Year 10		Comments
	IN	OUT	IN	OUT	IN	OUT	IN	OUT	IN	OUT	
PIPED SUPPLY SYSTEM											
River pumping											
Groundwater pumping											
Master meter adjustments (+/-)											
Corrected input volume											
AUTHORISED CONSUMPTION											
Water deliveries (metered)											
Water deliveries (unmetered)											
Line flushing (metered)											
Other uses (metered)											
WATER LOSSES											
Leakage on mains											
Leakage on service lines											
Metering inaccuracies											
Operational (theft, breaks)											
DRAINAGE											
Drainage											
Rain on drains											
Evaporation											
Seepage											
SHALLOW GROUNDWATER											
Leakage (pipes)											
Seepage (drains)											
Lateral outflow											
Capillary rise											
Watertable change											
DEEP GROUNDWATER											
Deep leakage											
Lateral outflow											
Deep pumping											

Leakage is usually the major component of water loss in piped irrigation systems. Other losses include operational (breaks, bursts, theft, cleaning/flushing of pipes) and all types of metering inaccuracies. Table 11 summarises these losses in the piped irrigation system.

Table 11: Summary of the total losses of piped irrigation at system and subsystem levels:

Type	Losses (ML)	Accuracy (%)
Leakage (main, laterals, service lines)		
Metering inaccuracies		
Operational		

4.4.1 Preliminary significance of the anticipated losses

Once a strategic water balance has been used to identify potential losses, the next step is to assess the economic and environmental significance of those potential losses.

A preliminary economic appraisal will include:

- the number of ML of water expected to be saved;
- the market value of water in the region; and
- estimated infrastructure costs (in many situations, it may not be possible to estimate this if it is not clear where and how losses are occurring).

This will lead to a rough assessment of cost per ML of water saved and a recommendation as to which losses should be the subject of further detailed investigation.

A qualitative differentiation of apparent and real water losses and gains, and an assessment of the likely environmental impact resulting from losses, need to be made by describing water pathways in the area. For example, some leakage losses from the piped systems may end up providing water to ecologically significant flora or fauna nearby. In these situations, there may be an apparent water loss from the pipes but not from the system as a whole.

4.5 Spatial prioritisation and sub-systems water balance

A sub network audit is used to measure volume flows across the network, for a subsystem water balance of piped systems. The network audit should measure flow volumes across the network to support the water balance calculation. It also helps to identify places in the system where water is being lost.

The United Kingdom National Leakage Initiative (1991–94) provided a model for understanding losses and developing solutions. Measurements for the network audit can be made in several ways:

- from existing production meters (calibrated or checked)
- from existing bulk meters
- from reservoir drop tests
- by checking pump curves or unmeasured production with insertion meters
- by checking metered consumption (sample of consumer meters checked for accuracy and under-registration at low flows)
- by checking operational use and unmeasured supplies.

4.5.1 Collecting and collating data for detailed investigations

This element focuses on identifying and quantifying the components of the subsystem water balance (particularly operational, leakage and unaccounted losses) of spatially prioritised areas using a range of technologies and methods.

The availability of data needs to be checked against the list given in Section 4.1. The data accuracy is checked against the methods used for data collection and calibration, record/performance testing of equipment and instruments, the operator knowledge, the purpose for which the data were collected, and the time period. Statistical and modelling tools can be used to validate the datasets.

If proper data are not available or their accuracy is not guaranteed, local water audit is used to measure volume flows across the subsystem. The network audit can allow people to measure volume flows across the network to support the water balance calculation. It also helps to know where the water is being lost from, within the irrigation system.

4.6 Description of modules

In piped systems, the water lost through all types of leaks, bursts and overflows on mains, service connections, service lines (up to the point of customer metering) is the main challenge. The modular format makes it possible to choose the combination of assessment approaches best suited to a particular situation at system and subsystem levels.

In a piped system, leakage and operational components are the identified losses. The location and extent of these losses can be identified through qualitative and quantitative techniques.

4.6.1 Leakage losses

Detailed investigation of leakage losses should use a combination of qualitative and quantitative techniques. Not all techniques will be necessary.

(a) Qualitative approaches include:

- characteristics of the noise of leaking water (see Section 4.8)
- acoustic logging (see Section 4.9)
- non-acoustic techniques (see Section 4.10)

(b) Quantitative approaches include:

- the step-testing technique (see Section 4.7)
- quantifying leakage losses at system level using ANN technique (Achim et al 2007, Boussabaine et al 1999) or statistical extrapolation and regression models (Kohzadi et al 1996, Ho et al 2002).

4.6.2 Operational losses

Detailed investigation of operational leakage losses should use a combination of qualitative and quantitative techniques. Not all techniques will be necessary:

(a) Qualitative approaches include:

- assessing unmeasured supplies (using operator knowledge).

(b) Quantitative approaches include:

- validating accuracy of metered deliveries (see Section 4.12).

4.6.3 Unaccounted flows

Detailed investigation of unaccounted flows should use a combination of qualitative and quantitative techniques. Not all techniques will be necessary.

(a) Qualitative approaches include:

- unmetered deliveries (using operator knowledge)
- unauthorised consumption (using operator knowledge).

(b) Quantitative approaches include:

- metering inaccuracies (meters need to be calibrated and checked using operator knowledge).
- master meter flow adjustments (+/-)

4.7 Step testing technique

The step testing technique involves two main methods:

- isolated method
- close and open method.

The isolated method involves the successive closing of valves starting from the furthest point from the meter. The sequence of closing valves is progressively carried out by working back to the meter where the flow should drop to zero. The close and open method involves closing valves to isolate each individual step and, once the reduction of flow has been recorded, reopening the valves. This technique is particularly useful when a leak creates little or no sound.

4.8 Characteristics of the noise of leaking water

Water leaking from a pressurised main emits sound over a range of frequencies and in most cases produces a hissing sound. Each leak produces its own specific distribution of noise frequencies, which depend on factors such as the type and size of leak, the pipe material, and the pressure and nature of the ground into which the water is escaping. The leak noise will travel through the wall of the pipe at a velocity that depends on both the characteristics of the pipe material and the water. This sound can also travel through the ground surrounding the pipe. As the sound travels away from the leak, the frequencies may change due to cavities in the ground or other buried pipes. However, not all leaks produce a detectable sound and different techniques may need to be used.

4.9 Acoustic logging

Acoustic logging detects sound not audible to the human ear. It does not require parts of the distribution system to be shut down. This detection is done using acoustic leak detection sounding equipment. After detection of a leak, further investigation before excavation is carried out. Loggers can be attached to GSM communication to report any leaks present.

Leak correlators then use the pipe parameters (material, diameter and length for fixing distance between sensors) to calculate the pipe velocity, which subsequently determines the precise location of leakage. Computerised leak correlators can help reduce wasted water by finding under-groundwater leakage.

4.10 Non-acoustic techniques

Non-acoustic techniques include the use of:

- ground-penetrating radar
- tracer gas
- infrared thermography
- visual leak detection.

4.10.1 Ground-penetrating radar

Ground-penetrating radar (GPR) is a non-intrusive, non-destructive technique that produces images similar to an X-ray, without the hazards of radiography. It is cost-effective due to minimal interruption of operations, and because it avoids the high costs of damage and repairs due to excavation. GPR has been used primarily for locating and surveying pipes, cables and other buried objects. GPR and a variety of cutting-edge digital electronics have the capability to scan and map the subsurface in real time. Mapping the results of subsurface investigations plotted on AutoCAD digital base maps provides useful information and water leaks can be found by observing the disturbed ground or cavities around the pipe.

4.10.2 Tracer gas

Gas injection and tracing techniques for locating leaks are not as commonly used now because of the advancement of acoustic techniques. However, this method is still applicable in low-pressure mains and small diameter pipes, especially non-metallic pipes. The leak is located by filling the pipe with tracer gas (industrial hydrogen - 95% nitrogen and 5% hydrogen or helium) that escapes at the point of the leak and is detected accurately with a ‘sniffing’ probe on the surface. The tracer gas has the advantage of dissipating through the soil above the pipeline very quickly. With more solid surfaces, such as concrete, the process is slower. This method requires skilled practitioners and expert contractors could carry out the work.

4.10.3 Infrared thermography

Water from the leak is of a different temperature from the surrounding ground and a thermographic camera can sometimes see this temperature discrepancy.

4.10.4 Visual leak detection

Visual leak-detection practices are used to make sure that leaks in remote areas do not go undetected. When surface water is found in the area of the water system, chlorine and fluoride tests are conducted to differentiate system leaks from water originating from rainwater and groundwater.

4.11 Metering Inaccuracies

All meters should be physically inspected. Selected meters should then be further analysed using flow rate recorders to assess their accuracy. Finally, a GIS database of the meter locations should be developed to facilitate the identification of meter assets that may be causing water loss.

5. REPORTING PARTITIONED LOSSES – THEIR LOCATION, EXTENT AND CAUSE

5.1 Partitioning water losses

Once the strategic water balance at a subsystem level is completed both spatially and temporally, the potential water savings are known. This process is partitioned into:

- gains and losses at the subsystem level;
- partitioning of the water losses—operational, leakage, evaporation and seepage (evaporation and seepage is only for open channel systems); and,
- opportunities for potential water savings.

This information should then be integrated at irrigation system level. This task can be assisted by a GIS based decision-support system.

5.2 Spatial prioritisation of partitioned losses

The prioritisation of the system to achieve the required results is of paramount importance to reduce cost, expedite the process and achieve the required goals. At the irrigation subsystem level, a GIS-based hydrological analysis would find the water lost out of the system. The spatial analysis coupled with the economic assessment would lead to establish the significance of losses for further investments. The economic appraisal includes:

- Volume (ML) of water expected to be saved
- Market value of water in the region
- Anticipated infrastructure costs
- Assessment of cost (dollars per ML) of water saved.

5.3 Project Data

The project data collected during the hotspots assessment should be in GIS format. This will make it easier to use in a channel-loss decision-support system, to guide what infrastructure could be improved or refurbished by the irrigation providers. Developing the GIS-based decision support tool will incorporate the following hotspots project data on a case-by-case basis:

- diversions
- deliveries
- channel and piped network — supply, drainage, rivers/creeks
- types of the infrastructure improvements

- delineation of major associated environmental assets
- boundaries — irrigation area, farms, crops/land use
- other infrastructure — roads, towns
- cropping/land use areas
- crop water use
- groundwater pumping in the irrigation areas
- piezometric levels
- water pathways — arrows indicating major inflows and outflows
- conveyance efficiency terms — losses, gains and escape flows
- soil information (texture and hydraulic properties)
- economic parameters of infrastructure improvements.

5.4 Reporting partitioned losses

A standardised format for reporting partitioned water losses at system and subsystem level includes:

- area description;
- data availability and accuracy;
- results of a whole-of-system water balance;
- results of local or subsystem water balance;
- economic significance of losses;
- environmental assessment of losses and anticipated improvements; and
- results of detailing location and quantum of water losses.

5.5 Conclusions

Water savings are only real where they do not affect the productive or environmental gains from the water lost. Real water savings must deliver further productive or environmental gains from the saved water. For example, some losses from the channels may recharge high water quality aquifers that provide water for drinking and for the environment. In these situations, there may be an apparent water loss from the channels but not from the system as a whole. Piping open channels may eliminate seepage and evaporation losses, but might have an effect on recreational uses of water in-stream. Targeting investments to such real water savings must ensure the best value for money. This aspect must be considered to determine the sustainability of investments during business (modernisation) planning processes.

APPENDIX A: INFLOW-OUTFLOW METHOD

Principle

The inflow-outflow method is a direct measurement of water losses in the supply channels. Based on a water-balance approach, it measures water flows at both ends of a channel section and considers additional inflows (rain) and losses (deliveries, evaporation) along the channel length during the period of investigation.

Applications

- The inflow-outflow method is used to estimate ‘first-cut’ seepage losses at the system level.
- It can be used at various scales, from a channel section to supply system level.
- It is difficult to get sufficiently accurate flow measurements for short channel sections with lot of diversions, and for channels with low flows.
- However, the method is suitable for identifying and prioritising channels with higher losses.
- Longer channel sections without diversions can be measured more accurately.
- It is suitable for assessing remediation in a long section of channel.

Method

The difference between inflow and outflow represents seepage and leakage, after accounting for inflows, outflows and known losses. Accuracy depends on inflow and outflow measurements, including gains and losses. A number of techniques are used, as shown in Figure 4, below:

- Current meters are used to measure an average velocity. Discharge is estimated by multiplying the velocity with the cross-section area of the channel.
- Flow measuring equipment is available to measure direct flows even in irregular cross- sections, e.g. earthen open channel or a river section.
- Existing regulating structures, such as flumes or weirs, with automatic recording gauges at the channel section are used.

Standards / Calibration

Method is based on a water balance approach and enables direct measurement of losses.

The flow measurement devices need to be calibrated against pre-calibrated flow regulating structures like flumes and weirs.

Water loss estimates are best over long sections, without diversions; however, it is difficult to have an indication of spatial variation of losses within the section monitored.

Estimated cost

Depending the type of meter used, the cost varies from around $1500–$3500 per kilometre of channel length

These costs include data collection, analysis and reporting, and exclude travel and logistic costs. Two to three channel sections per kilometre can be monitored in a day, depending on the site accessibility and flow conditions in the channel.

(a) (b) (c)

Figure 4: Flow measurements using (a) a current meter, (b) FlowTracker, and (c) RiverCat

Timeframe

The estimate depends on flow conditions in the channel. The indicative time is three days per five kilometres of channel reach.

Further reading

IAL. 2008. http://www.irrigation.org.au/seepage/11_how.html

Khan S, Akbar S, Rana T, Abbas A, Robinson D, Dassanayake D, Hirsi I, Blackwell J, Xevi E, Carmichael A. 2005. Hydrologic economic ranking of water savings options. Murrumbidgee valley water efficiency feasibility project. Consultancy Report to Pratt Water Group. CSIRO Land and Water, Griffith, NSW, Australia.

APPENDIX B: PONDAGE TEST

Principle

The pondage test is considered the most accurate method for assessing channel seepage (see Figure 5). It uses a water-balance approach to determine seepage losses in an isolated section of channel. Seepage losses constitute the drop in water level over a time in the selected section, after accounting for evaporation, rainfall, and other inflows and outflows. This is a direct method for measuring the losses through a section of channel. As such, it is considered to be a datum for benchmarking and assessing other methods.

Applications

- It is used as a standard for comparing other channel-seepage quantification methods.
- The method provides more accurate estimates of losses in shorter channel sections without diversions.
- It can be used at various scales, ranging from a channel section to a whole irrigation system.

Method

The selection of channel reach may be determined by geophysical surveys (EM31, geo-electrical resistivity surveys). The selected channel section is blocked off with embankments at each end and filled with water to full-supply level or slightly higher. As the water level in the channel section falls, the level is measured either by a staff/hook gauge or a water-level recorder for a fixed time. The seepage loss rate is computed after taking into account necessary corrections for evaporation & rainfall.

(a) (b)

Figure 5: Pondage test for measuring water losses: (a) channel is blocked on both ends, and (b) construction of embankment in progress

Standards / Calibration

Bank survey is essential and a minimum length of 50m is recommended. Clay barriers on both ends of the channel section are compacted and lined to prevent horizontal seepage. A rainfall gauge and evaporation pan is essential. Water levels are measured at multiple points within the channel.

Estimated cost

The most significant cost of the pondage test method is building the embankment. This cost varies considerably depending on proximity of a suitable clay source to the selected channel reach. For channels 10–20 metres wide and 1.5–2 metres deep, embankment construction costs range from $1000 to $1200 each. Associated surveying costs range from $600 to $2000 for every 200 metres.

Timeframe

- The typical duration of a pondage test is 4–10 days.
- The duration of the test depends on the amount of measured seepage.
- The test should be cancelled in the event of excessive rainfall.

Further reading

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APPENDIX C: SEEPAGE METERS

Principle

A seepage meter uses a watertight bell housing that is embedded into the channel bed. The water lost per unit area through the base of this bell is the seepage loss from the channel. A seepage meter is used for point test seepage measurement. The infiltration rate has a direct relationship to the seepage at the measuring point. Each point test provides an individual value and these are collated for identifying seepage hotspots and relative seepage potential. Many point measurements are usually required to capture the spatial infiltration variability. Seepage meters (see Figure 6) are best suited for determining the relative seepage losses over short reaches of channel.

Applications

- Seepage meters are best suited for defining water loss hotspots.
- They are generally not reliable for absolute quantification of channel seepage losses due to the variable nature of soil and channel beds.

Method

Various types of seepage meters are available.

(a) (b) (c)

Figure 6: Measuring seepage using the Idaho seepage meter: (a) schematic view of seepage meter, (b) installing the meter in the channel, and (c) measuring seepage

Standards / Calibration

Seepage meters are installed with the least possible disturbance of the bed material.

This method requires a large number of tests to obtain a representative seepage rate over a given length of channel. Seepage meters can be used when channel is operational.

Estimated cost

The seepage meter needs a skilled operator. The greatest variable influencing the cost of point measurement is the density of tests in the channel. The cost provided is a rough guide only:

Seepage Meter — 22 sites (four individual tests at each site over the channel cross-section): $6200.

Timeframe

The time required to cover 20–25 sites per kilometre of channel length is 4–5 days, excluding travel time.

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APPENDIX D: GROUNDWATER MONITORING

Principle

Regular monitoring of groundwater observation bores provides a permanent record of aquifer response to seepage. Using groundwater bores is not considered accurate for quantifying channel seepage, because of spatial variability of hydraulic conductivity and because bores do not locate the channel seepage. A high density of bore transects would be required for meaningful identification of local seepage areas. Groundwater monitoring (see Figure 7) is a valuable part of the site characterisation phase during a channel seepage investigation.

Applications

- Groundwater monitoring can be used to identify and quantify seepage.
- It is mostly applicable at local-scale investigations, but requires many wells and regular monitoring.
- It reflects the actual operating (dynamic) conditions and directly identifies channel seepage.
- Observation bores are permanent tools for measuring the seepage effects.
- Channel operations are not interrupted and all sizes of channel can be studied.

Method

The method requires a minimum of two groundwater observation bores at right angles on either side of the channel. The lower end of the piezometer (PVC pipe) is screened by making slots depending upon the bore depth. The slots are covered with linen (socks) to keep slots free from clogging. As the water table rises and falls, the level of water in the piezometer also rises and falls. Watertable monitoring is carried by a tape measure, float or measuring stick. Regular monitoring is done by loggers. The pre-channel groundwater level is estimated by assuming a constant gradient between the bores. In addition, an estimate of the aquifer hydraulic conductivity is also required and can be determined by a slug test.

(a) (b) (c)

Figure 7: Piezometers are used for monitoring the watertable: (a) drilling bores, (b) installation, and (c) a set of piezometers

Standards / Calibration

The measuring tape or measuring stick must be thoroughly checked for any breakage and length units to be used. Any adjustment of the measuring tape because of plopper / bell at the end must be made. The measuring instruments should be suspended vertically.

Laboratory calibrations of the new loggers are carried out by the manufactures and the accuracy is given. However, there is a need for the individual calibration depending on the level of accuracy required. It is recommended that the probe is checked and cleaned periodically, depending on the soil and water conditions that the probe is exposed to.

Estimated cost

Costs vary according to the scale of the investigation, which can range from $8000 to $10,000. Drilling bores and installing piezometers may cost $200–$300 per metre, depending on the lithology.

Timeframe

The actual behaviour of ground flows needs long-term monitoring, which may last 9–12 months.

Further reading

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APPENDIX E: REMOTE SENSING

Principle

Remote sensing is a promising way of providing a first-cut identification of potential seepage sites. Thermal imaging using airborne or satellite technology is an emerging and promising technique for evaluating channel conditions and detecting leaks in a qualitative way. The main hypothesis is that soil moisture levels along the channel are higher in areas of seepage, and soil moisture conductivity influences the thermal characteristics of the soil, which is visible in thermal images. Several studies conclude that moist sites (channel leakage areas) emit more radiation during the evening hours and less radiation during the periods of peak incoming solar radiation than low moisture sites.

Applications

- Remote sensing is a tool for identifying channel banks with high leakage rates.
- The channel operations are not affected.
- Further analysis is required for quantifying seepage.
- Remote sensing should be used for identifying lateral seepage only, not vertical seepage.

Method

Thermal imagery (in video format) is captured using a thermal infrared camera mounted on a helicopter that flies over selected channels (see Figure 8). The video is processed to produce individual images for identifying sites with potential leakage problems. Later, those sites are inspected to see whether they are leaking. Remotely sensed image data sources may include:

- thermal photography
- airborne high-resolution sensor data
- satellite imagery.

Standards / Calibration

Remote sensing data needs to be validated against on ground observations. Raw data needs corrections to satellite data and to remove the effect of noise. The data must be validated against on ground observations

Geometric Correction: Geo-correction process involves the extraction of the aircraft roll, pitch, yaw and GPS data.

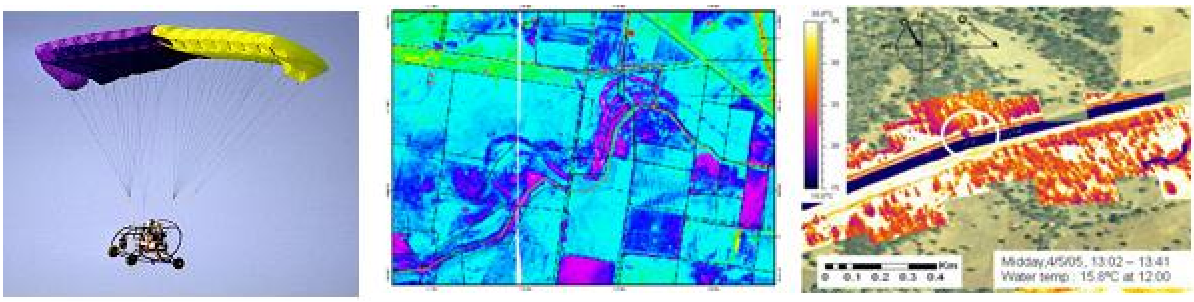
Atmospheric Correction: Adequate atmospheric and radiometric corrections be applied to bring all scenes to a common radiometric datum.

Radiometric Correction: This enables consistent image interpretation where the radiance values for each pixel for each band are represented in spectral radiance units ($\mu W\ cm^{-2}\ sr^{-1}\ nm^{-1}$).

Sensor degradation as well as inter-platform differences has to be taken into account in calibration.

Estimated cost

Suitable quality airborne infrared data (3–5-metre resolution) for three lengths of channel (10–20 kilometres each) costs around $11,000. Data-processing costs, including integration with a GIS system, are approximately $5000–$10,000.



(a) (b) (c)

Figure 8: Remote sensing tools: (a) flying drone with thermal imager, (b) seepage/prior stream locations in Jemalong, and (c) thermal imaging in West Corurgan

Timeframe

The total time to acquire the data, analyse and report can take several months.

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APPENDIX F: ELECTROMAGNETIC SURVEYS

Principle

A number of electromagnetic (EM) induction techniques can be used to measure the EM properties of the soil profile (see Figure 9). However, the penetration depth depends on both the soil lithology and the salt content of any water in the soil. Clay soil is more conductive than sandy soil due to its chemical structure. EM techniques are used in two ways:

- for identifying hotspots by mapping the distribution zones into high and low-seepage zones
- for quantifying seepage rates by integrating EM values with other data (including depth to groundwater, salinity, and hydraulic conductivity) and carrying out numerical analysis using an artificial neural network (ANN) model.

The relative seepage rates can be compared by correlating EM data with other data, particularly seepage determined by point measurements and pondage tests. EM induction techniques include EM31, EM34 and EM38 with signal penetration depth of 6, 7.5–30 and 1–1.5 metres respectively. Another new instrument is EMP-400, where up to three frequencies can be selected to record three effective depths of penetration.

Applications

- EM surveys provide opportunities for the rapid, non-invasive mapping of landscape parameters, such as salinity or aquifer texture.
- There is no interruption in channel operations and continuous spatial assessment is provided.
- Technical expertise is required to interpret the results.

Method

The seepage assessment is made by moving an EM instrument along the channel banks. The focus of EM imaging is several metres below the ground surface:

- for shallow watertables (surface to approximately five metres), EM31 is suitable for direct seepage detection.
- for watertables deeper than five metres, EM34 (in vertical dipole mode) can be used.

Standards / Calibration

EM systems are calibrated for each soil type. Soil ECa is used to establish soil core sampling locations needed for calibration. The geospatial EM data is calibrated against the observed sample data using geostatistical techniques.

EM31 surveys along channels length shows that ECa is highly variable along their length and result into ECa zones.

Estimated cost

- EM31: for on-land survey, four traverses on each side of the channel (over three sites): $600–$1000 per kilometre.
- EM34: for one traverse only: $500–$1000 per kilometre for both sides of channel.

(a) (b) (c)

Figure 9: Electromagnetic surveys: (a) supply channels of Murrumbidgee Irrigation Area, (b) EM31 mounted on a quad bike, and (c) EM38

Timeframe

The total time to acquire the data, analyse and report can take three to four weeks per kilometre of channel length.

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APPENDIX G: GEO-ELECTRICAL RESISTIVITY SURVEYS

Principle

Direct-current geophysical resistivity is used for subsurface characterisation. It measures the distribution of electrical resistivity in the subsurface. Each measured resistance is an average of the electrical properties of both solids and liquids in the hydrogeological system. The resistivity is imaged from one meter below the ground down to a few tens of meters. The depth of penetration depends on the electrical properties of the subsurface, electrode spacing, and local noise. After data inversion, a tomogram (or X-ray) shows the distribution of electrical resistivity in the subsurface — a physical property directly related to rock type, porosity, and the ionic strength of the pore fluids.

Applications

- The subsurface provides reasonably straightforward targets for resistivity methods.
- Distortion of the electrical field by conductivity variations due to salinity, texture or moisture content can be imaged vertically at various depths.
- The floating geo-electric array can be towed behind boats, along rivers and irrigation channels, to map the resistivity of underlying sediments of the channel bed.
- It is particularly effective in mapping seepage of highly saline groundwater and evaluating the effectiveness of salt interception schemes.
- In static land surveys, direct contact with the surface is needed (which is problematic in areas with resistive ground cover).

Method

The water bottom is continuously recorded to help plot the resistivity and water layer in relation to depth (see Figure 10). The electrode cable consists of a number of stakeouts for injection current and for the reception of potentials. The near-surface lithology of the channel bed is mapped, and, in turn, yields information about channel seepage hotspots by comparing fresh water resistivity with resistivity standards for various soils and rocks. The data are downloaded, graphically visualised and processed for any errors. Finally, the data are exported to RES2DINV software for inversion modelling and interpretation. RES2DINV develops pseudo-section inversion to true resistivity 2D section.

Standards / Calibration

The equipment is calibrated against different soil formations. There are defined ranges of apparent resistivity values for each formation. The resistivity depends upon soil type, degree of saturation and the salinity level of both soil and water.

Estimated cost

- Waterborne (marine) surveys: $2500–$3500 per day with average channel coverage of 10 kilometres per day.
- Land static surveys: $3500–$4500 per day with average coverage of one kilometre per day.
- Processing is $80–$100 per hour.

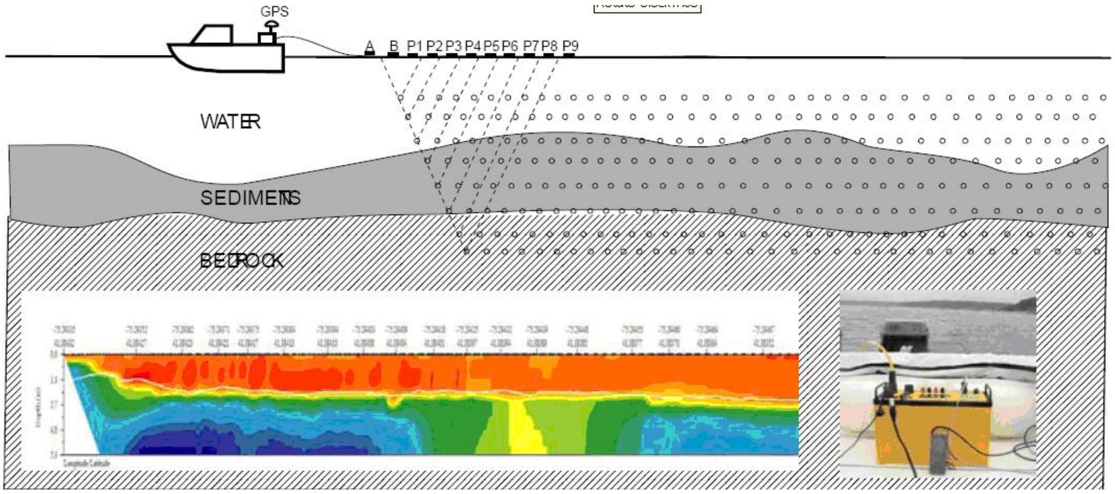

Figure 10: Schematic view of geo-electrical surveys in the channel system

Timeframe

The total time to acquire the data, analyse and report can take one week for every 20 kilometres of channel length.

Further reading

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APPENDIX H: AIRBORNE ELECTROMAGNETIC SURVEYS

Principle

Airborne electromagnetic (AEM) surveys map the bulk electrical conductivity of geological material down to depths of greater than 100 metres. They are useful for identifying channel reaches that are recharging aquifers, and the distribution of salt stores relative to the surface drainage network. Saline water is more conductive than fresh water. In surveys of saline groundwater aquifers, the low-conductivity signals are interpreted as a fresh groundwater plume caused by leakage from the supply systems.

Applications

- Airborne surveys are a cost-effective method of obtaining regional survey information from the sub-watershed scale to basin scales.
- They can be implemented in either the frequency or time domain and on a helicopter or fixed-wing aircraft.
- Apparent resistivity maps are related to hydrogeological features, such as depth to groundwater and aquifer characterisation.
- They can be used to map the distribution and depth to the saline water over very large areas and have been used over thousands of square kilometres in Australia.

Method

The instrument is designed for hydrogeological and environmental investigations. It is unique in its ability to acquire accurate data where resistivity contrasts can be 50–80 ohm-m. The results can guide subsequent ground surveys that are used for more detailed investigation. Airborne surveys are contracted; raw data, maps and profiles are delivered for interpretation (see Figure 11).

Standards / Calibration

The equipment is calibrated against different soil formations. There are defined ranges of apparent resistivity values for each formation. The resistivity depends upon soil type, degree of saturation and the salinity level of both soil and water.

Estimated cost

- Base prices for collecting and processing high-resolution magnetic and radiometric data are about $6 per line kilometre.

- Aerial data costs about $5 per hectare for fixed-wing systems and about $10 per hectare for helicopter-mounted systems. Costs for hiring the helicopter and processing are additional.

(a) (b) (c)

Figure 11: Airborne electromagnetic surveys: (a) schematic of the instrument, (b) SkyTEM in use on a helicopter, and (c) AEM image in Lower Balonne catchment

Timeframe

It can take several months to coordinate the surveys.

Further reading

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GLOSSARY

Aquifer

An aquifer is an underground layer of water-bearing permeable rock or unconsolidated materials (gravel, sand, silt, or clay) from which groundwater can be usefully extracted using water wells.

Apparent loss

In piped systems, apparent loss consists of errors in accounting, inaccurate customer meters, illegal connections and bypassed meters.

In open-channel systems, apparent losses include water that moves from one system to another, such as water that percolates into deep aquifers and water that moves from a river into adjacent aquifers.

Artificial neutral network

An artificial neural network, often just called a ‘neural network’, is a mathematical model or computational model based on biological neural networks.

Authorised consumption

Consists of subcategories that include all authorised water use:

Bottom-up water balance

A water-balance calculation that quantifies individual water balance components at the smallest known scale and aggregate it using the scale of interest.

Conveyance efficiency

In an irrigation system, conveyance efficiency is the ratio between the volume of water delivered at the farm-gate level to the volume diverted from the river to the irrigation supply network.

Corrected input volume

The sum of master meter accuracy and system input volume is the amount of water that was actually put into the system.

Efficiency

The ratio of input to output in any system is the efficiency. Efficiency in an irrigation system consists of various components and takes into account losses during storage, conveyance, distribution and application to irrigated paddocks. Efficiency can be measured at the scale of the whole catchment, at the individual plant scale, and at almost any level in between.

Electromagnetic induction survey

Measurement of the apparent conductivity of the subsurface by recording the response of electrical properties of soils induced by pulsing a current through a fixed or mobile loop.

Environmental assessment indicators

Indicators that measure: water quantity used; soil cover; spatial extent of shallow groundwater table and quality; pH, land disturbance, threatened and protected species in the area; wetlands; vegetation and revegetation and wildlife rescue impacts; weed control; willingness to pay/accept for improved environmental amenity, such as achieving more natural river flow regimes; and ecotourism revenue per dollar of investment.

Escapes

Water lost as overflow from an irrigation channel system. The volume of escaped water is directly related to the volume of water ordered per farm but not taken at the farm-gate level. Inaccurate off-take diversions also contribute to escaped water. Escaped water is not necessarily a real loss because it may be used further downstream.

Evaporation

The physical process by which water is transformed to vapours. Evaporation loss occurs in channels and storages and is a real loss.

Evapotranspiration

Evapotranspiration is a term used to describe the sum of evaporation and plant transpiration from the earth's land surface to the atmosphere. Evaporation accounts for the movement of water to the air from sources such as the soil, canopy interception, and water bodies. Transpiration accounts for the movement of water within a plant and the subsequent loss of water as vapour through stomata in the plant’s leaves.

Geophysics

The earth science that uses the principles and methods of physics to measure the physical properties of soil and rock to infer composition and structure.

Groundwater

Water located beneath the ground’s surface in soil pore spaces and in the fractures of rock formations.

Hotspot

A point in an irrigation supply system where relatively intense water loss, through leakage or seepage, operational, and evaporation, is taking place.

Infiltrometer

An instrument that determines the rate and amount of water percolating into the soil by measuring the difference between the amount of water applied and that which runs off.

Input volume/water delivery

All the water that is purchased, owned, or obtained by interconnects (water imported).

Irrigation efficiency

The ratio between the volume of water used by plants through evapotranspiration to the total volume of water applied through effective rainfall, irrigation, and capillary flow in the irrigation system.

Leakage

The loss of water from channels through channel banks and structures.

Lithology

The physical characteristics of rock, with reference to qualities such as colour, composition and texture.

Master meter accuracy

Obtained by calibrating master (i.e. key off take and major flow meters). The utility checks the accuracy of the master meters and then either adds or subtracts this number, depending on whether the meter was under or over-registering, from system input volume to determine the amount of water that was actually put into the distribution system.

Operational loss

The water loss during distribution of irrigation water from an irrigation supply system to the field channel network.

Piezometer

A small-diameter water well used to measure the hydraulic head of groundwater in aquifers.

Pondage test

A water-balance approach to measure channel seepage and leakage within an isolated reach of a channel. A section of channel is blocked off with embankments and filled with water. The seepage and leakage rate is calculated from the rate of water decline after corrections are made for evaporation and rainfall.

Real loss

In piped systems, real loss consists of all types of leaks, bursts, and storage tank overflows that occur before the customer's meter.

In open-channel systems, real water loss is the water lost from one part of water cycle, which can no longer be used in a beneficial way in another part of the hydrologic cycle (e.g. evaporation and fluxes to the saline sinks).

Remote sensing

Gathering information about an object or phenomenon by using either a recording or real-time sensing device(s) that is not in physical or intimate contact with the object (such as by way of an aircraft, spacecraft, satellite, drone, or ship).

Resistivity survey

A geophysical technique used to measure the apparent resistivity of the subsurface by applying a direct current to the ground and measuring the resultant ground potential and current in the vicinity of the applied current.

Saturated zone

The area below the watertable where all open spaces are filled with water under pressure equal to, or greater than, that of the atmosphere. The watertable is the top of the saturated zone in an unconfined aquifer.

Seepage

Seepage is the movement of water through the beds of irrigation channels. Seepage losses are 'real' losses when seepage flows to saline groundwater and becomes unusable.

Seepage meter

A covered cylindrical infiltrometer fixed with a polyethylene bag filled with water. Seepage meters are used for spot measurements of seepage in earthen channels.

Strategic water balance

The sum total of inflows and outflows in the irrigation system.

Top-down vs bottom-up water balance

The "top-down" water balance starts at the irrigation system level and disaggregates different components of flows to a lower level of detail only if necessitated by the purposed of the project. The "bottom-up" water balance starts with the description of the lower level processes (for example crop water balance or channel seepage) and scales up or aggregates these process to the irrigation system level to develop the system water balance.

Transpiration

The process by which water vapour escapes from a living plant, principally through the leaves, and enters the atmosphere. In field crops, evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes.

Water exported

Water that is transferred out of the system to a buyer where revenue is received.

Water loss

Comprised of apparent loss and real loss. Corrected input volume minus authorised consumption equals total water loss.

Water supplied

Defined as system input volume minus water exported.

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