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Replenishing alluvial groundwater in the Lockyer Valley

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To date, consensus has not been reached regarding the mode of replenishment of alluvial groundwater in the Lockyer Valley and, as a result, it has not been possible to impose a sustainable management regime. A management strategy must be based on a sound understanding of the resource and how it is replenished. Once a consensus has been reached, it should then be explained to the general public seeking its approval. This paper is an attempt to provide such an explanation.

It is proposed that the water which replenishes the alluvial groundwater falls as rain on the basaltic uplands in the south and west of the Valley. It infiltrates and some deep percolates to aquifers in vesicular layers of basalt lava where it is stored temporarily and is moved laterally to springs which release it to the land surface at an elevation of about 500 m above sea level. This springflow moves quickly to creeks where, prior to irrigation in1937 it flowed throughout the creek system as perennial running water (also termed baseflow). This water is then absorbed into sand/gravel aquifers in alluvium which convey it laterally towards alluvial margins to wherever it is needed to replenish water extracted for transpiration by Eucalyptus trees or for irrigation. This lateral movement continues provided the flow of springflow in creeks is maintained. The water table is raised when water is drawn up into the unsaturated soil above it by capillarity.

The Lockyer Valley water supply is an example of a finely-balanced, complex, natural water supply system which has not been described elsewhere in the world's hydrology literature. It would be surprising if similar examples do not exist elsewhere.

System components

The main components of the system are rainfall on the Main Range, two sets of aquifers linked by baseflow in creeks (Galletly 2007) and aquitards in the alluvium from which water is extracted for irrigation of some 12 000 ha. This aquitard water is replenished by water supplied by creeks. Some of the components and the processes involved are as follows.

Annual rainfall

Rainfall on the arable alluvium (700 – 800 mm/annum, 7 – 8 ML/ha/annum) is the main source of water for crop production. However, it is erratic and supplementary irrigation is required to enable crops to be established on time; to nurse them through short dry periods and to bring them to maturity. The primary source of supplementary water is rainfall (1000 – 1200 mm/annum) on the 65 450 ha of rugged basaltic landscape on the Main Range, and 1 000 mm of rainfall has a volume of 654 500 ML. The volume of irrigation water required annually to supplement rainfall on the alluvium may be close to 5% of the rainfall on the basalt: 32 725 ML. This volume has yet to be measured.

Basalt aquifers

Most of the rain on the basaltic landscape at the top of the Main Range infiltrates into the shallow permeable soil and is used as evapotranspiration by the eucalypt forest. Less than 5% deep percolates to several layers of vesicular basalt in the basalt lava which are aquifers. The layers of vesicular basalt are interconnected by cracks in the basalt mass.

Spring flow

The basalt groundwater is moved laterally by gravity and is discharged almost continuously from hundreds of springs at about 500 m above sea level on to steep sandstone landscape. It then moves quickly to creeks where it is concentrated and has been termed baseflow (outflow from groundwater aquifers). It will be termed springflow here as this word indicates its origin.

Prior to the advent of irrigation in the Lockyer Valley the duration of springflow in creeks was close to 360 days/annum. Only a small proportion was discharged into the Brisbane River near Lowood. The volume of median springflow discharged has been estimated at some 24 000 - 30 000 ML/annum providing 2 – 2.5 ML/ha of irrigation water on 12 000 ha.

Alluvial aquifers/aquitards

The springflow in creeks is absorbed into sand/gravel aquifers some 3-5 m deep in the base of the alluvium and is moved slowly in aquifers toward the alluvial margins. The rate of water flow in these aquifers is slow because of their shallow depth; the small head of water in creeks and the low hydraulic gradient toward aquifer margins. Long flow durations, sometimes more than one year, are required to move water to the margins of the downstream alluvium.

Most of the groundwater held in the alluvium is held in soil which was deposited on the floodplain when creeks overflowed during floods. This material (termed an aquitard – the less permeable beds in a stratigraphic sequence) is unable to transmit water laterally under natural hydraulic gradients but allows water to move vertically downward during pumping.

The fertile, irrigable soils which have formed on the most recent deposits are finer still with higher clay contents. They are unable to transmit water laterally. Almost all of the rain which infiltrates is held by capillary forces in the top one metre of soil where it is used by plants.

Alluvial groundwater: use and replenishment

Under natural conditions, the main form of water loss from alluvial groundwater was by transpiration by the blue gum forest. This caused the water table (the surface of the saturated alluvium) to fall slightly, thereby decreasing the transpiration rate. Since about 1940, most of the water removed from the alluvium has been pumped for irrigation, lowering the water table by some metres. Replenishment occurs when water is drawn up from the saturated surface into the unsaturated soil above it by capillarity. This is the suction force causing water to move up against the force of gravity in capillary tubes with a diameter of less than one millimeter: the size of the pores in the aquitard (soil) (Keen 1931). Capillarity acts continuously, but upward movement occurs only when water is being supplied, and so replenishment depends on the duration and volume of springflow in creeks.

Replenishment is maximised when the surface area (ha) of the underground lake is large; when the volume of springflow (ML/annum) is sufficient to replace the water lost in the previous season; and when the duration of spring flow (days/annum) is close to 365 days/annum, as it was prior to the commencement of irrigation.

Estimating sustainable use

To date, it has not been possible to devise a method of using Lockyer groundwater sustainably, mainly because the nature and functions of the initial store are not understood and the volume of water available for use annually has not been determined. The volume of water available annually is that which is delivered in creeks as springflow (baseflow) during one year. Each groundwater basin has an ‘optimum basin yield’ which is slightly less than the ‘maximum stable basin yield’. A problem arises because, in the Lockyer Valley, the main irrigation season is from April to October while the main replenishment season is from November to March, during summer rains. During the irrigation season, the rate of water use exceeds the rate of replenishment so the water table is drawn down slightly, usually by less than one metre. Prior to the mid-1960s, the volume of water extracted for irrigation was less than the volume available for replenishment, so water levels were fully restored by the beginning of the next irrigation season, giving the impression that the supply was inexhaustible. It is not. There is an upper limit to the volume of water which is delivered from the springs in basalt in one year – possibly in the range 24 000 – 30 000 ML/annum

Sustainable yield easily exceeded

Because the volume of replenishment is not known in advance, it has to be estimated. Also, because Lockyer Valley irrigation depends on groundwater rather than surface streamflow in creeks, it is critical that groundwater be restored throughout the alluvium: not just in areas close to creeks. The water which replenishes the water used for irrigation does not become usable water for irrigation until it is incorporated into the initial store of water. Experience over the past 45 years has shown that farmers are easily able to use 4 ML/ha if it is available so that, if the area of land used for irrigation is 12 000 ha, the water demand could be as high as 48 000 ML/annum which is more than the basalt aquifers are capable of delivering in one year. Also, because groundwater is replenished by streamflow in creeks, it is essential that this flow be maintained for close to 365 days per year, otherwise insufficient time is available to transfer water from the creeks to the alluvial margins in downstream areas where the alluvium is widest. This has not happened over the past 45 years because pumping directly from creeks has been permitted, so reducing the volume and duration of downstream flow and reducing downstream groundwater replenishment.

Required measurements

The volume of water available for irrigation in any season must be estimated in advance using past experience as a guide. Because we have no means of estimating rainfall in the coming year, the estimate will always have some error, so it is better to under-estimate the volume available in the forthcoming season (and so maintain the initial high water table level) than to over-estimate it (and cause the water table to fall). The only known way of making this estimate in a groundwater basin is to measure (meter) the volume of water extracted for irrigation (and other uses) as ML/annum and, concurrently, to determine the effect of this level of extraction on the average depth of saturation (m) in the alluvium at, say 3-month intervals, to determine whether the current rate of extraction is causing the average depth of fall, rise, or remain stable. If the water table in the alluvium continues to fall, the rate of extraction is too high and must be reduced.

At the present time in the Lockyer Valley, it is well known that the water table is lower than it was before irrigation began in the 1940s, so it will be desirable to extract less than the optimum basin yield (say 90%) for some years to enable the water level to rise to its former level. The present yield of the system under this regime may be termed the ‘net present sustainable yield’ (NPSY) and its volume should be determined annually. It can be expected that the maximum groundwater yield from the system will be achieved when the water table is restored to the level it was at say, in 1950. When this level is reached, the area (ha) of alluvium underlain by groundwater will then be at its maximum as will be the volume (ML/annum) of water being drawn up into the unsaturated aquitard above the water table by capillarity.

The following arithmetic is provided to illustrate the calculations required to distribute the available water to farms using the principles of distributive justice. Measured volume of water use: 24 000 ML/annum. Area of land on the alluvium underlain by groundwater: 12 000 ha. Nominal valley allocation: 2 ML/ha. Area of irrigable land on a given farm: 70 ha. Interim (October) water allocation for the following year: 140 ML. Final allocation (varied according to summer rainfall) 1.95 ML/ha: 136.5 ML. Using this arrangement, all farmers would then be able to plan their irrigation in the next season and apply modern water scheduling procedures.

Conclusion

It is concluded that the water supply for irrigation on the Lockyer Valley alluvium is provided by springflow which is outflow from basalt aquifers on the Main Range. This gives the long-duration flow which provides the time required for water to be transported from creeks to the margins of the alluvium through sand/gravel aquifers in the base of the alluvium. The groundwater which was extracted for irrigation is replenished when water is drawn up from the water table into the unsaturated soil above by capillarity.

Because of the long-duration flow provided by springflow, the average flow rate required is quite small. Flow rates are usually quoted as m^3/s. There are 31 558 000 seconds in one year so an average flow of 1 m^3/s supplies a volume of 31 558 000 m^3 or 31 558 ML/annum, which may be close to the estimated optimum basin yield of the system. An important aim of water management should be to restore streamflow duration to close to 365 days per year.

References:

Galletly, JC 2007, *Baseflow in the Lockyer Creek*, PhD thesis, University of Queensland, Gatton Campus.

Keen, BA 1931, *The physical properties of the soil*, Longmans, Green and Co. London

Glossary

Alluvium. Material deposited by a river on its bed and banks and on the neighboring land which is covered with water in times of flood. The deposits on the bed tend to be coarser than those on the floodplain.

Aquifer. A saturated, permeable, subterranean geologic unit that is able to transmit water laterally a distance of 100 m in less than 120 days (0.33 years) under natural hydraulic gradients.

Aquitard. The less permeable, saturated, subterranean geologic strata which are able to transmit water more slowly, moving a distance of 100 m in 0.33 to 33 years. Most soils are aquitards.

Aquiclude. Almost impermeable, saturated, subterranean geologic strata which are unable to move water laterally under ordinary hydraulic gradients. It would take more than 33 years to move water 100 m.

Basalt. A dark coloured, igneous, volcanic rock which was fluid lava when extruded as magma, and often has vesicular layers where gas bubbles have expanded to form cavities 3-9 mm in diameter and so is able to store and transmit large quantities of water underground.

Baseflow. Natural, prolonged, clear, surface outflow of rain water from groundwater aquifers.

Capillarity. Unbalanced electrical forces due to surface attraction causing fluids to rise and be held in tubes or pores less than 1 mm in diameter against the force of gravity.

Deep percolation. Drainage of soil water below the soil profile through permeable strata.

Evapotranspiration. Loss of water from plants and soil by evaporation and transpiration.

Hydrology. The science which deals with all aspects of water movement on the earth.

Hydraulic head. The pressure due to the head (depth - m) of water above a given point.

Hydraulic gradient. The slope (%, m/m) on the water table in the direction of flow.

Infiltration. Movement of water into the surface of soil.

Matric potential. The (negative) pressure potential force resulting from the attraction of water to a soil matrix, enabling water to be held in the surface layers of soil against the force of gravity.

Percolation. Movement of soil water downward through the soil profile.

Sandstone. Sedimentary rock derived from the disintegration of older rocks, usually laid down in horizontal strata under water.

Spring. Springs are openings through which ground water, driven by gravity, reaches the surface.

Springflow. Surface water flow derived from groundwater discharged via springs (see Baseflow).

Unsaturated zone. The portion of a porous medium (such as a soil, aquifer or aquitard) in which the pores are not completely saturated with water.

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