Walling, D. E., and He, Q., 2002. Using 137Cs measurements to test distributed soil erosion and sediment delivery models. In Summer, W., and Walling, D. E. (eds.), *Modelling Erosion, Sediment Transport and Sediment Yield*. Paris: UNESCO, International Hydrological Programme.

White, W. R., 2000. *Contributing paper flushing of sediments from reservoirs*. Prepared for thematic review IV.5: operation, monitoring and decommissioning of dams. Cape Town: World Commission on Dams.

White W. R, and Bettess R., 1984. The feasibility of flushing sediments through reservoirs. In *Proceedings of the Harare Symposium*, July 1984, Harare. IAHS Publication No. 144, pp. 577–587.

Xiaoqing, Y., 2003. *Manual on sediment management and measurement*. Operational Hydrology Report 47. Geneva: UNESCO, World Meteorological Organization.

Xing, J., Alan, M., and Davies, A. M., 2002. Influence of wind direction, wind waves, and density stratification upon sediment transport in shelf edge regions: The Iberian shelf. *Journal of Geophysical Research*, **107**, 3101, doi:10.1029/2001JC000961. 24 pp.

Yang, C. T., and Molinas, A., 1982. Sediment transport and unit stream power. *ASCE, Journal of Hydraulic Division*, **108**, 774–793.

Cross-references

Nasser Lake
Reservoir and Lake Trap Efficiency
Reservoir Sedimentation
Xiaolangdi Reservoir's Role in Water and Sediment Regulation

RESERVOIR SEDIMENTATION IN AUSTRALIA UNDER EXTREME CONDITIONS

Hubert Chanson
School of Civil Engineering, The University of Queensland, Brisbane, QLD, Australia

Introduction

Since the early European settlements in Australia, the coastal and continental development of the country has been coupled with the availability of water supply. Today, the country's economy remains highly dependant upon its surface irrigation, and more than 85% of water diversions are for agricultural purposes (irrigation and stock watering only). Any reduction in water storage caused by reservoir siltation, and the associated loss of fertile soil, is a critical parameter with economical and political impacts. There has been, however, some conflicting information on whether reservoir siltation has been significant in Australia. Indeed, for many years, reservoir sedimentation has not been an issue: "the (sediment) yield [. . .] is relatively low compared to others in the world" (Outhet 1984, NSW Water Resources Commission); the classical text book *Open Channel Flow* by F. M. Henderson, University of Newcastle NSW, made no mention of reservoir siltation in Australia in the section "Sediment transport" (Henderson, 1966). The issue of reservoir siltation in Australia was ignored and rejected until the late 1970s despite some implications in terms of dam safety (Chanson, 1998; Chanson and James, 1999).

Herein, a reanalysis of existing data and new information on extreme reservoir siltation in Australia is presented. It is shown that several extreme siltation events took place and affected predominantly small to medium size reservoirs. It is the purpose of the study to present new comparative data and to develop new compelling conclusions regarding reservoir sedimentation in Australia.

Hydrology of the Australian continent

Australia is a large continent (7,690 E + 3 km^2) of low relief (Figure 1). Its most prominent topographic feature is the Great Dividing Range, a chain of low mountains and tablelands extending over 2,500 km along the eastern and southeastern coastlines.

Although the average annual rainfall is about 420 mm, the spatial and temporal variability is high. The rainfall may vary from zero for several years during droughts to extreme hydrological events (e.g., 515 mm in 6 h at Dapto NSW, in 1984). The average runoff is only 13% of the rainfall, varying from 0 mm in most Western Australia to over 700 mm in some regions of Eastern Australia and Tasmania (Department of Natural Resources, 1976). Indeed, evaporation is high. Average annual standard pan evaporation exceeds 1,000 mm in nearly all parts of the continent, with extreme evaporation above 3,000 mm in Central Australia.

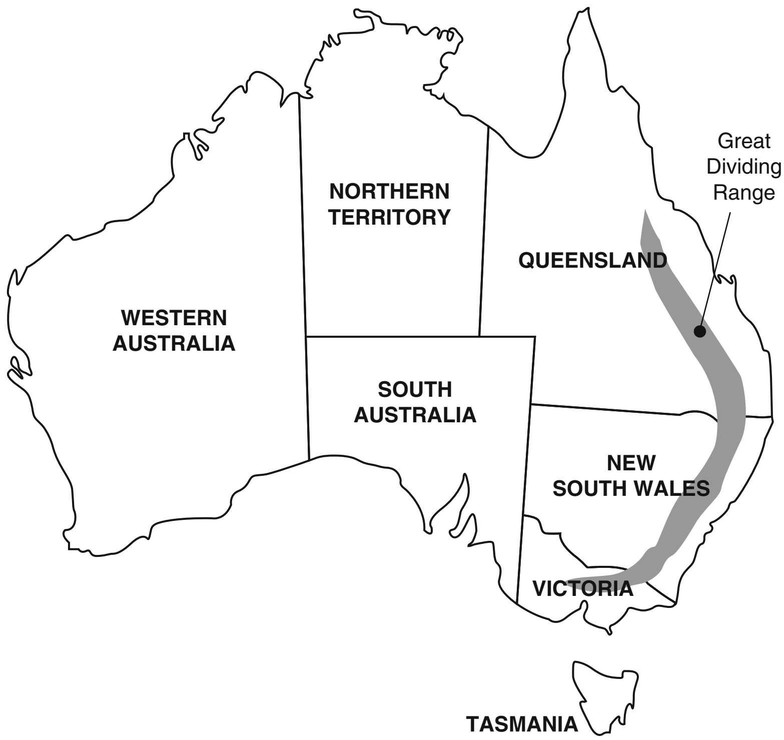
High evaporation coupled with the variability of surface runoff make conservation and development of surface water resources more expensive, less effective, and more political than in many countries.

Extreme reservoir siltation in Australia

Between 1890 and 1960, more than 20 reservoirs (excluding farm dams) became fully silted in Australia, most in New South Wales (Table 1). The writer investigated personally several reservoir siltation cases (Figures 2–5). Fully silted reservoirs included town water supply reservoirs (e.g., Moore Creek dam), railway dams (e.g., Gap weir), and mining reservoirs (The railway dams were built to supply water to the steam engines for the railway. Steam engines were in use in Australia up to the 1970s.).

Examples of reservoir siltation

Completed in 1888 (first dam) and around 1890 (second one), the Sheba dams were designed to supply water to the gold mines of the Mount Sheba Company, near Nundle NSW located next to the edge of the Great Dividing Range. The upper dam is an earth embankment (7.6 m high, 91 m long), and the reservoir area is 5 acres. The lower dam is also an earthfill structure (6.1 m high, 64 m long) with a 4-acre reservoir area. The dams are located at high altitude, nearly 1,100 m, on the western side of



Reservoir Sedimentation in Australia under Extreme Conditions, Figure 1 Map of the Australian continent.

Reservoir Sedimentation in Australia under Extreme Conditions, Table 1 Major reservoir siltation in Australia

Reservoir (1)	Location (2)	Completion date (3)	End of use (4)	Purpose (5)
Sheba dams	Nundle, NSW	1888	– (*)	Mining (two dams)
Corona	Broken Hill, NSW	1890	1910 (*)	Irrigation
Laanecoorie	Maryborough, VIC	1891	Still in use	Irrigation
Stephens Creek	Broken Hill, NSW	1892	Still in use	Town water supply
Junction Reefs	Lyndhurst, NSW	1896	1930? (*)	Hydropower for mining activities
Moore Creek	Tamworth, NSW	1898	1924 (*)	Town water supply
Gap	Werris Creek, NSW	1902	1924 (*)	Railway supply
Pekina Creek	Orroroo, SA	1907	1984	Irrigation and town water supply
de Burgh dam	Barren Jack, NSW	1908	–	Railway and town water supply
Koorawatha	Cowra, NSW	1911	– (*)	Railway supply
Pykes Creek	Ballan, VIC	1911	Still in use	Irrigation and water supply
Pekina Creek	Orroroo, SA	1910	1930s (*)	Town water supply
Cunningham Creek	Harden, NSW	1912	1929 (*)	Railway supply
Illalong Creek	Binalong, NSW	1914	1985? (*)	Railway supply
Umberumberka	Broken Hill, NSW	1915	Still in use	Town water supply
Melton	Werribee, VIC	1916	Still in use	Irrigation
Korrumbyn Creek	Murwillumbah, NSW	1918	1924? (*)	Town water supply
Borenore Creek	Orange, NSW	1928	Still in use	Railway supply and town water supply today
Quipolly	Werris Creek, NSW	1932	1955 (*)	Railway supply
Inverell	Inverell, NSW	1939	1982 (*)	Town water supply
Arrona Gorge dam	Leigh Creek Town, SA	1950	–	Mining and town water supply

Chanson (1998).
NSW New South Wales, QLD Queensland, SA South Australia, VIC Victoria, WA Western Australia
(*) reservoir fully silted today, (–) information not available.

the Great Dividing Range, and water was collected on both the western and eastern slopes of the Range. The dams are fully silted and used for trout fishing and as touristic attraction. There are some safety concerns because the spillways are inadequate.

Built around 1905–1907, commissioned in 1911, the Pekina Creek dam is an earthfill structure, 24 m high after the heightening in 1914. Located near Orroroo SA, it was designed to supply irrigation and town water. The original reservoir capacity was 1.54 E + 6 m^3 (after 1914 heightening), and the catchment area is 136 km^2. More than 50% of the reservoir was silted in 1944, and the sediment volume accounted for 60% of the initial capacity in 1971. The reservoir was disused in 1964 (McQuade et al., 1981).

The Koorawatha dams, located near Koorawatha NSW, were a railway dams, designed to supply water to the steam engines for the nearby railway line, opened in November 1886 and closed in 1980. Two thin-arch concrete dams were built successively at the same site. The first dam was 5–7 m high, and it is located 5–10 m upstream of the present dam (Figure 2). The crest was still visible during dry periods up to the 1930s although, today, it is underneath the dry reservoir bed. Completed in 1911 (or 1913?), the second Koorawatha dam is a concrete single-radius arch (9 m high, 0.92 m thick at crest, 40-m arch radius). The upstream wall is vertical, and the downstream face is battered. The weir was equipped with an outlet system and an overfall spillway (24 m long, 0.3 m high). The reservoir is fully silted today, occupied by sand and gravels, suggesting sedimentation by bed-load (Figure 2).

Reservoir Sedimentation in Australia under Extreme Conditions, Figure 2 Dry reservoir of Koorawatha weir, railway dam completed in 1911 – view from the right bank in December 1997.

Completed in 1928, the Borenore Creek dam was built to supply water to the Orange-Broken Hill railway line. The dam is a concrete single-radius arch wall (17 m high, 123 m long at crest, 1.12-m crest thickness) (Figure 4).The catchment area is 22 km^2, and the original storage capacity was 230,000 m^3. The dam was equipped with an outlet system and an overfall spillway. Interestingly, a new outlet (pipe inlet) was installed, later, about half-height of the dam, as a result of the reservoir siltation which amounted for 150,000 m^3 in 1981 (Figure 4). After being used by the NSW Railway Department, the dam has been used as the town water supply for Molong. The reservoir is used only as an emergency reserve today.

Completed in 1916, the Melton dam is an earth and rockfill embankment, and it was heightened in 1937 and 1967. The reservoir was built for irrigation purposes. The initial reservoir capacity of 21.0 Mm^3 was increased to 23.6 Mm^3 in 1937. The catchment area is 1,098 km^2. During the 1930s and 1940s, the reservoir suffered heavy siltation caused by cattle and sheep grazing, gold and coal mining, and rabbit colonies in the catchment. In 1941, when the reservoir was nearly empty, a heavy rainstorm filled the reservoir in 36 h and the spillway was heavily used. (The reservoir inflow was estimated at 1,444 m^3/s.) Massive siltation took place during the event, and a 2.6-m thick silt deposit was left on the spillway intake after the flood. In 1945, the reservoir capacity was reduced down to 19.1 Mm^3. Erosion control works were carried out, including construction of check dams, furrowing works, and elimination of vermin. In 1968, the reservoir siltation amounted for 6.6 Mm^3 of sediments.

The old Quipolly dam or Quipolly dam No. 1 was completed in 1932 to supply town water for Werris Creek NSW, irrigation water and water for steam engines (Figure 5). The dam is a concrete single arch (19 m high, 184 m long crest), the catchment area is 70 km^2, and the original storage capacity was 860,000 m^3. The reservoir suffered heavy sedimentation between 1941 and 1943 (Chanson and James, 1998). The reservoir was disused in 1955, and the reservoir is fully silted today. The reservoir acts now as a sediment trap for the new Quipolly dam (Quipolly dam No. 2) located downstream.

Comparison between Australian and overseas siltation rates

A comparative analysis of the siltation rates with overseas experience suggests that the reservoir sedimentation

Reservoir Sedimentation in Australia under Extreme Conditions, Figure 3 Fully silted reservoir of Cunningham Creek railway dam (Harden NSW) completed in 1912 – view from the right bank in December 1997.

Reservoir Sedimentation in Australia under Extreme Conditions, Figure 4 Borenore Creek dam completed in 1928 – view from the left bank in December 1997. Note the old scour outlet system and the new water intake at half-height of the dam wall.

rates in Australia were high (Table 2). Table 2 compares the most extreme (well-documented) siltation events in North Africa, North America, Asia, Europe, and Australia. These data are summarized in Figure 6, showing extreme siltation rates as a function of the duration of the study.

Figure 6 suggests that highest (recorded) siltation rates are observed during short duration studies (1–10 years).

Reservoir Sedimentation in Australia under Extreme Conditions, Figure 5 Fully silted reservoir of Old Quipolly dam (Werris Creek NSW) completed in 1932 – view from the right bank in June 1997.

There is, however, a lack of information on long-term siltation over 70 years. Note further that the data indicate the net sedimentation rate, after flushing. In several cases where flushing was used, the real sediment inflow rate was much larger.

Among the extreme events, the cases of the Shihmen reservoir, the El Ouldja dam, and the Sweetwater reservoir are peculiar. The Shihmen dam (Taiwan Republic of China) is a 133-m high dam built between 1958 and 1964. The maximum reservoir capacity was more than 60,000,000 m^3, and the catchment area is 763 km^2. Although the dam was inaugurated in 1964, the reservoir began filling in May 1963. In September 1963, 20,000,000 m^3 of silt accumulated during cyclonic floods (typhoon Gloria).

The El Ouldja dam was a debris dam built to protect the main Oued Djenden dam (Algeria). The siltation of the reservoir was studied in details between 1947 and 1950 (Duquennois, 1951). The results highlighted siltation by bed-load material with sizes ranging from 1 mm to over 0.5 m and heavily loaded turbidity currents of silt and clay (density between 1,100 and 1,300 kg/m^3).

Built between 1888 and 1887, the Sweetwater dam was designed to supply irrigation and town water to the San Diego area (USA). The catchment area is 482 km^2, and the original reservoir capacity was 20 E + 6 m^3. Heavy siltation took place during the January 1895 flood, and it was well documented (Schuyler, 1909).

In Australia, the sedimentation of Quipolly reservoir between 1941 and 1943 was an extraordinary event. Overall, most sedimentation problems in Australia were experienced with small to medium size reservoir (catchment area less than 100 km^2 typically). In contrast, large Australian reservoirs have not been sedimenting rapidly at the exception of Melton and Eildon reservoirs. Heavy siltation at Eildon was experienced in 1940 during torrential rainfalls, following bushfires which destroyed more than 50% of the forest in the catchment (Joseph, 1953).

Today, lower siltation rates are experienced in Australia, especially since the 1950s. It is believed that the reduction in sedimentation is related to the introduction of new farming techniques, new land conservations practices, and an awareness of soil erosion problems. The same trend is experienced in the New South Wales, Victoria, South Australia, and Queensland states (Figure 1).

Discussion: Climatic changes and flushing devices

Interestingly, the records suggest that the most extreme siltation periods in Australia took place during major floods following an El Niño event and long droughts. Such extreme siltation events were experienced at the Junction Reefs reservoir (1902 floods after the Great Drought of 1900–1902), the Moore Creek reservoir (flood of February 1908), the Gap weir (floods of 1919), the Melton reservoir (flood of 1941), and the Quipolly reservoir (floods of 1942–1943).

The drought periods in Australia may be extremely severe. The most severe drought occurred between 1895 and 1903, 1902 being the severest year. During this period, the sheep numbers declined by more than 50% and cattle by more than 40%. Recently, a decade of drought persisted between 1958 and 1968, and between 2000 and 2008.

The world community has focused its attention on the early detection of drought (*El Niño*) which is termed a "major catastrophe" in the television news. But the El Niño phenomenon, also called El Niño Southern Oscillation phenomenon (ENSO), takes place in average every 5–7 years. It is a *recurrent* climate pattern which is not properly managed by local, national, or international institutions. No contingency for long-term policy has been made.

Sediment flushing devices (or lack of)

Surprisingly, the Australian reservoirs have been inadequately equipped with flushing devices (Table 3). Most

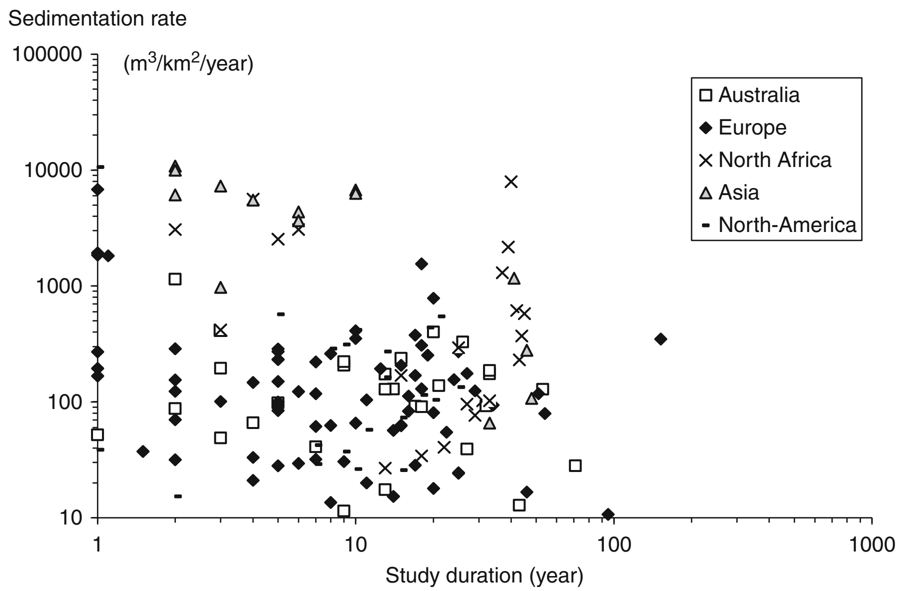
Reservoir Sedimentation in Australia under Extreme Conditions, Table 2 Examples of extreme reservoir siltation rates in Australia and overseas

Reservoir (1)	Sedimentation rate (m^3/km^2/year) (2)	Study period (3)	Catchment area (km^2) (4)	Annual rainfall (mm) (5)
Asia				
Wu-Sheh (Taiwan) (*S*)	10,838	1957–58	205	–
	9,959	1959–61	205	–
	7,274	1966–69	205	–
Shihmen (Taiwan) (*S*)	4,366	1958–64	763	> 2,000
Tsengwen (Taiwan) (*S*)	6,300	1973–83	460	3,000
Muchkundi (India)	1,165	1920–30?	67	–
North Africa				
El Ouldja (Algeria) (*W*)	7,960 (*F*)	1948–49	1.1	1,500
El Fodda (Algeria) (*W*)	5,625 (*F*)	1950–52	800	555
	3,060 (*F*)	1932–48	800	555
Hamiz (Algeria) (*W*)	1,300	1879–1951	139	–
El Gherza (Algeria)	615	1951–67	1,300	35
	577	1986–92	1,300	35
North America				
Sweetwater (USA)	10,599	1894–95	482	240
White Rock (USA)	570	1923–28	295	870
Zuni (USA) (*)	546	1906–27	1,290	250–400
Roosevelt (USA)	438	1906–25	14,900	–
Europe				
Saifnitz (Austria) (*)	6,820	1876	4	–
Monte Reale (Italy) (*)	1,927	1904–05	436	–
Wetzmann (Aust.) (*)	1,852	1883–84	324	–
Pont-du-Loup (France) (*)	1,818	1927–28	750	–
Pontebba (Austria)	1,556	1862–80	10	–
Lavagnina (Italy)	784	1884–1904	26	1,800
Roznov (Poland) (*S*)	398	1958–61	4,885	600
Cismon (Italy)	353	1909–19	496	1,500
Abbeystead (UK) (*)	308	1930–48	49	1,300–1,800
Porabka (Poland) (*S*)	288	1958–60	1,082	600
Australia				
Quipolly (*)	1,143	1941–43	70	686
Pykes Creek	465	1911–45	125	–
Umberumberka	407	1961–64	420	220
Corona (*)	400	1890–1910	15	–
Eildon	381	1939–40	3,885	–
Moore Creek (*)	174	1911–24	51	674
Pekina Creek (*)	174	1911–44	136	340–450
Korrumbyn Creek (*)	1,400 (?)	1918–24?	3	1,699

Chanson (1998), Chanson and James (1998), Chu (1991), Cyberski (1971), Lajczak (1994), Orth (1934), Rowan et al. (1995).
(*S*) Summer rainfall climate, (*W*) Winter rainfall climate, (*F*) Important flushing, (*) fully silted reservoir, (?) uncertain data, (–) Data not available.

Australian reservoirs were equipped with a single-scour outlet (∅ = 0.3 to 0.5 m), inadequate to desilt a reservoir. Only few dams were equipped with two or more flushing systems e.g., the Illalong Creek dam completed in 1914 and now fully silted.

In comparison, the Nabataeans, Romans, and Spaniards equipped their reservoirs with large sediment flushing system. (The Nabataeans were the habitants from an ancient kingdom to the East and Southeast of Palestine that include the Neguev desert. The Nabataean kingdom lasted from around B.C. 312 to A.D. 106. The Nabataeans built a large number of soil and retention dams. Some are still in use today.) For example, the Roman engineers equipped the Monte Novo dam (A.D. 300, Portugal) with two outlets of 1.2 and 1.4 m^2 cross-sectional area each. Such an expertise in sediment flushing, gained over the past 22 centuries, was obviously unknown to, or forgotten by, the Australian engineers.



Reservoir Sedimentation in Australia under Extreme Conditions, Figure 6 Extreme siltation rates (m^3/km^2/year) as a function of study duration (year).

Reservoir Sedimentation in Australia under Extreme Conditions, Table 3 Scour outlet systems

Dam (1)	Year of compl. (2)	H (m) (3)	Catch. area (km^2) (4)	Reserv. capac. (m^3) (5)	Bottom outlets (6)	Outlet area (m^2) (7)
Nabatean dam						
Sabra valley dam, Jordan	BC 100	4.6	–	3,600	1 outlet	0.49
Roman dams						
Kasserine dam	BC 100	10	–	–	Vaulted outlet tunnel	4
Örükaya dam, Çorum, Turkey	AD 200	16	–	–	Vaulted bottom outlet	3
Çavdarhisar dam, Kütahya, Turkey	AD 200	7	–	–	Vaulted bottom outlet	11
Monte Novo, Evora, Portugal	AD 300	5.7	2.9	–	2 outlets (1.2 and 1.4 m^2)	2.6
Spanish dams						
Almansa dam, Spain	1384	15	–	2,800,000	2 water outlets + 1 scour outlet (1.95 m^2)	2.95
Alicante (Tibi) dam, Spain	1594	41	–	5,400,000	1 water outlet + 1 scour outlet (5 m^2)	6
Elche dam, Spain	1642–45	23.2	–	400,000	vertical outlet + scour gallery	–
Relleu dam, Spain	1650–1776?	28	–	600,000	large scour gallery	–
Puentes dam, Spain	1791	50	–	52,000,000	2 water outlets + scour gallery (51.1 m^2)	>52
Australian dams						
Moore Creek dam, Australia	1898	18.6	51	220,000	1 pipe outlet + 1 scour valve	~0.1
Gap weir, Australia	1902	6–10	160	–	No outlet	0
Korrumbyn Creek dam, Australia	1919	14.1	3	27,300	1 pipe outlet + 1 scour valve	0.04
Old Quipolly dam, Australia	1932	19	70	860,000	1 pipe outlet + 1 scour valve	~0.2

Chanson (1998), Saladin (1886), Schnitter (1971), Smith (1971).
Year of compl. year of completion, *H* dam height, *Catch. area* catchment area, *Reserv. capac.* reservoir capacity.

Conclusion

The main findings of the present review are: (1) the reservoir sedimentation has been a major problem in Australia, and (2) the Australian engineers could draw upon local and overseas experience, and from past failures. Indeed several reservoirs (Table 1) became fully silted because the designers did not take into account correctly the soil erosion and sediment transport processes, and no soil conservation practice was introduced.

Today the society expects the useful life of a reservoir to be more over 30–50 years. One lesson from past experience is the need to consider the dam, the reservoir, and the catchment as a complete system which cannot be dissociated. Soil erosion and water runoff lead into the streams some sediment material that is trapped downstream by the dam wall. A total catchment management policy must be considered from the early stage of a reservoir design.

The fully silted reservoirs stand as a source of embarrassment for the scientists and the public (Figures 2–5). Each reservoir failure must be a valuable teaching and pedagogic tool to heighten the awareness of students, professionals and local authorities, and of the public. Society must learn from its mistakes, not to repeat them again!

Acknowledgments

The writer thanks Mr. and Mrs. Chanson, Paris, France, Ms. Chou Y.H., Brisbane, QLD, and Mr. D.P. James for their assistance.

Bibliography

Chanson, H., 1998. Extreme reservoir sedimentation in Australia: a review. *International Journal of Sediment Research, UNESCO-IRTCES*, **13**(3), 55–63.
Chanson, H., and James, P., 1998. Rapid reservoir sedimentation of four historic thin arch dams in Australia. *Journal of Performance of Constructed Facilities, ASCE*, **12**(2), 85–92.
Chanson, H., and James, D. P., 1999. Siltation of Australian Reservoirs: some Observations and dam safety implications. In *Proceedings of the 28th IAHR Biennial Congress*, Graz, Austria, Session B5, 6 pages (CD-ROM).
Chu, Y. Y., 1991. Soil conservation and the use of Hillslopes in the Shihmen Watershed, Taiwan. In Moldenhauer W. C., et al., (ed.), *Development of Conservation Farming on Hillslopes.* Ankeny Iowa: Soil and Conservation Society, pp. 284–293.
Cyberski, J., 1971. Accumulation of debris in water storage reservoirs of central Europe. In Ackermann, W. C., White, G. E., Worthington, E. B., and Loreena-Ivens, J., (eds.), *Proceedings of the International Symposiumon Man-Made Lakes, Their Problems and Environmental Effects,* Knoxville TN: ICSU, (also in "*Man-Made Lakes: Their Problems and Environmental Effects*" Washington: AGU Publ., 1973, pp. 359–363).
Department of Natural Resources, 1976. *Review of Australia's Water Resources 1975*. Canberra, Australia: Australian Government Printing. 170 pp.
Duquennois, H., 1951. "Etude Statistique des Apports Solides et de leur Evacuation par Courants de Densité (Underflow)." ("Statistic Research on Solid Sediments and their Draining Off by Underflow.") In *Proceedings of the 4th ICOLD Congress*, New Delhi, India, Vol. IV, Q. 14, R. 47, pp. 119–135.
Henderson, F. M., 1966. *Open Channel Flow*. New York: MacMillan.
Joseph, O. F. F., 1953. "Siltation of Reservoirs. Eildon Surveys Analysed." *Aqua*, Nov., pp. 19–23.
Lajczak, A., 1994. The rates of silting and the useful lifetime of dam reservoirs in the Polish Carpathians. *Zeitschrift für Geomorphologie*, **38**(2), 129–150.
Mcquade, C., Hartley, R. E. R., and Young, G. J., 1981. *Land Use and Erosion in the Catchment of the Pekina Reservoir, South Australia. Report 4/81*, South Australia: SA Dept. of Agriculture.
Orth, F., 1934. Die Verlandung von Staubecken. ("The Siltation of Reservoirs."). *Bautechnik*, **12**(26), 345–358.
Rowan, J. S., Goodwill, P., and Geco, M., 1995. Temporal variability in catchment sediment yield determined from repeated bathymetric surveys: Abbeystead reservoir, U.K. *Physics and Chemistry of the Earth*, **120**(2), 199–206.
Saladin, H., 1886. Rapport sur la Mission Faite en Tunisie de Novembre 1882 à Avril 1883. *Archives des Missions Scientifiques et Littéraires*, Ministère de l'Instruction Publique, France, Serties 2, vol. 13, pp. 1–225 (in French).
Schuyler, J. D., 1909. *Reservoirs for Irrigation, Water-Power and Domestic Water Supply*, 2nd edn. New York: Wiley.
Smith, N., 1971. *A History of Dams*. Peter Davies, London: The Chaucer Press.

Cross-references

Australia, Climate and Lakes
Reservoir Sedimentation
Xiaolangdi Reservoir's Role in Water and Sediment Regulation

RESERVOIRS IN GREAT BRITAIN

Reginald W. Herschy
Hydrology Consultant, Reading, UK

Introduction

The development of large impounding reservoirs in Britain was mainly due to the necessity of feeding the canals constructed during the first phase of the industrial revolution (1750–1850). It was not until 1868, however, that civil engineers began to carry out research on reservoir storage when the subsequent design of impounding reservoirs replaced the use of early natural lakes for water supply.

Early-nineteenth-century reservoirs almost invariably had earthen embankments with central clay puddle walls, a construction that was known and used before 1800.

Later, impounded reservoirs were formed mainly of masonry or concrete including buttress dams of mass concrete made possible by the invention of Roman cement by Dobbs in 1810 followed by Aspdin's improved patent for Portland cement. These important inventions led to the first British Standard in 1904 (BS 12). The BS stipulated clear requirements with regard to safety measures in design and improved manufacturing techniques. However, the dam disaster in Wales in 1925 led to the Reservoirs (Safety Provision) Act of 1930, which made clear the dangers to reservoirs and the necessary precautions.

ENCYCLOPEDIA OF EARTH SCIENCES SERIES

ENCYCLOPEDIA *of* LAKES AND RESERVOIRS

edited by

LARS BENGTSSON
Lund University
Sweden

REGINALD W. HERSCHY
UK

RHODES W. FAIRBRIDGE

Springer

Library of Congress Control Number: 2012939385

ISBN: 978-1-4020-5616-1
This publication is available also as:
Electronic publication under ISBN 978-1-4020-4410-6 and
Print and electronic bundle under ISBN 978-1-4020-5617-8

Springer Dordrecht, Heidelberg, New York, London

Printed on acid-free paper

Cover photo: Maligne Lake/Spirit Island, Jasper National Park.
© Alberta Color Productions, Edmonton, AB, Canada

Every effort has been made to contact the copyright holders of the figures and tables which have been reproduced from other sources. Anyone who has not been properly credited is requested to contact the publishers, so that due acknowledgement may be made in subsequent editions.

All rights reserved for the contribution *Wetland Areas and Lakes in Bulgaria*

© Springer Science+Business Media B.V. 2012

No part of this work may be reproduced, stored in a retrieval system, or transmitted in any form or by any means, electronic, mechanical, photocopying, microfilming, recording or otherwise, without written permission from the Publisher, with the exception of any material supplied specifically for the purpose of being entered and executed on a computer system, for exclusive use by the purchaser of the work.