The construction and use of canal regulators in Ancient Sumer*

Richard J.W. Dight – Alhaurín el Grande

[This paper discusses the purpose, structure, method of operation, irrigation potential and distribution of regulators in Ancient Sumer. A regulator adjusts the volume of water entering the main irrigation canal. The water is then separated into smaller canals by divisors (káb-kud's) until the volume is reduced sufficiently to water individual fields.]

The Purpose of Regulators

Regulators were used in the delta area of the Tigris and Euphrates rivers to divert water from the main channels, which varied in depth during the flood season, into man-made canals that needed a maximum constant flow rate in order to irrigate the largest area of arable land.

The water regime in the delta, which sustained the early Sumerian civilisation, is different hydrologically from that further North where the later Assyrian Empire developed. At the delta the two rivers divide into a number of branches that frequently change course. The delta channels then meander across the delta plain and the flow is contained between natural 'levees', which can be over-topped in years when the floodwater is high. The annual rise in water level reaches its peak during April, May and June.

The mean height of the annual flood of the Euphrates in recent times (1928-32) was 5.5 meters, with a high of 6.39 m and a low of 2.36 m.[1]

In Nebuchadrezzar's time (605-562 BC) the quay at Babylon had steps to reach the water level which allowed for a rise and fall of 4.9 m. Also at Babylon, 'wear on the arches of the North Citadel drain vaults indicates a mean, normal and maximum levels, a difference of c. 4 m.' [2]

* I must express my gratitude to Professor William Holmes (Wye, London) and Professor Piotr Steinkeller (Harvard) for making helpful comments on the draft paper. Also Dr Manuel Molina (Madrid) for making the library facilities at the Instituto de Filología (CSIC) available to me, without which the paper would have had a much longer gestation period.

1. M. G. Ionides, *The regime of the Rivers Euphrates and Tigris*, London 1937, p. 95.

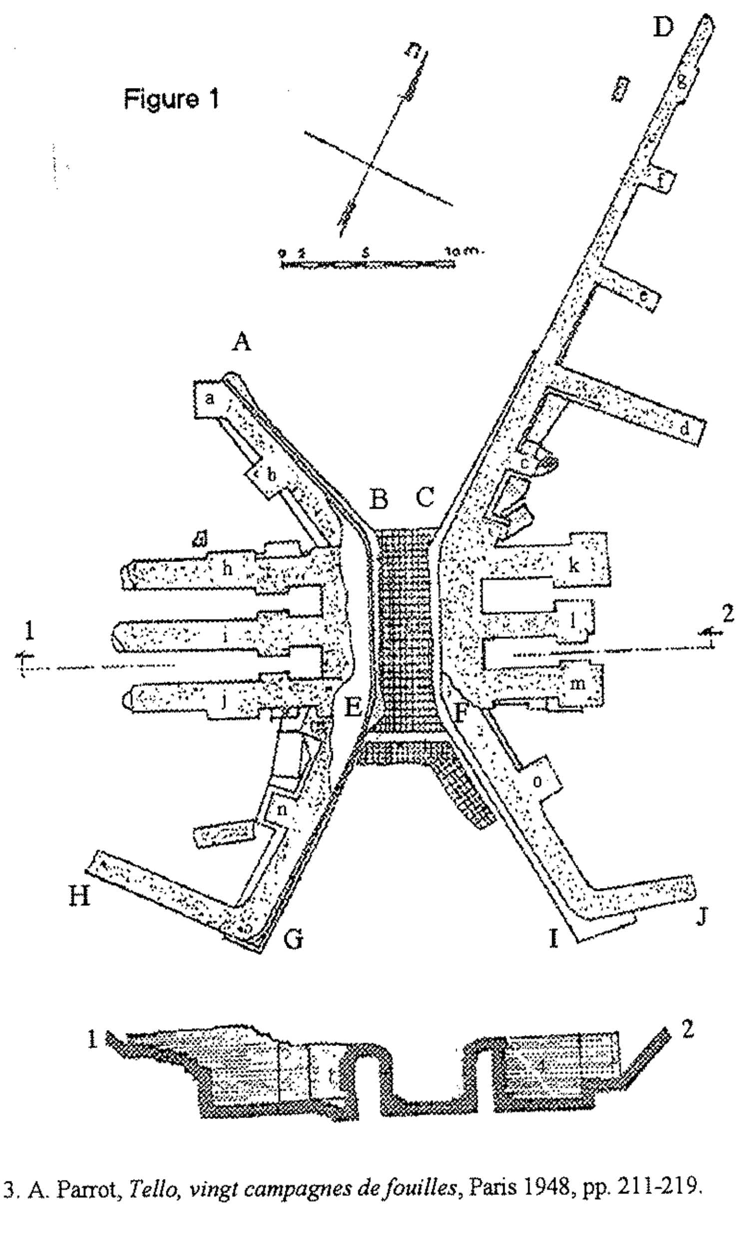
2. D. J. Wiseman, *Nebuchadrezzar and Babylon*, Oxford 1985, pp. 51 and 57.

It therefore appears that to obtain the maximum potential irrigation water over the whole of the flood period the regulators would have had to cope with variations between 4 and 6 meters of river level, and exceptional floods higher than this.

The Structure of Regulators

The archaeological evidence for the construction of regulators in ancient Sumer is limited to one site at Tello, the ancient town of Girsu. This was revealed in excavations carried out from 1929 to 1932 by de Genouillac and Parrot but they failed to understand its purpose and described it as a 'hypogeum'. It became known as the 'construction énigmatique'.[3]

Figure 1



3. A. Parrot, *Tello, vingt campagnes de fouilles*, Paris 1948, pp. 211-219.

Jacobsen[4] while describing the canal systems around Ur wrote that the 'construction énigmatique' was a weir, and compared it to the much later Sassanian and Islamic period weir at Shadhurwan-al-asfal on the Naharwan canal. However he did not show how it worked and a later paper by Barrelet[5] refuted his conclusions.

Pemberton *et al.*[6] supported the views of Jacobsen and described a modern regulator in Yemen, but this bears little resemblance in its working to the ancient one at Girsu.

The Girsu regulator was placed on the eastern bank (levee) of an affluent of the Euphrates, the Id-Nina-gena canal, which flowed from North to South.[7] The original plan published by Parrot[8] is shown in *Figure 1* with a revised notation.

The structure was made entirely of baked bricks bonded with bitumen. Soundings made in two places during the excavations discovered a foundation of bitumen impregnated reeds under the brickwork. Bricks of various sizes were used in different parts of the structure, but this has no significance to its strength or mode of action.

The brickwork walls A-B and C-D are protecting the clay and silt of the bank from erosion. The internal piers a, b, c, d, e, f and g are buttresses that add strength to the walls. These walls (A-B and C-D) are set at an angle and funnel water into the sluice made of walls B-E and C-F. These walls are buttressed by piers h, i, j and k, l, m. The floor of the sluice is made of six courses of brick laid on a bed of reeds and bitumen. The sluice measures 11.4 m x 3 m. From the section in *Figure 1* the walls of the sluice are about 5 m high, bricks may have been pillaged from the top of the structure so it is possible that the sluice could have been deeper. This would enable the regulator to cope with most flood conditions, and provide water from April to June.

The walls E-G-H and F-I-J supported by piers n and o form a fan that directs the water into a canal approximately 16 m wide.

During the excavations the soil that originally formed the riverbank was removed and the structure revealed. The soil from between the piers was compacted clay ('un massif de terre très fortement battue') and contained few but important artefacts, twelve clay cones of Gudea dedicated to nine deities and a single tablet of Ug-me. The sluice was filled with loose material containing many whole and broken objects.

The clay cones and single tablet of Ug-me were translated by Nougayrol.[9] He used these with other texts found at Tello to establish the chronology of Lagash. The regulator was dated at approximately 2150 BC. Nougayrol's translation of the tablet reads that Ug-me ' ...giš kéš.du (le réservoir?) du canal Ur-sag-a-ni a fait' and establishes that giš kéš.du is the Old Sumerian word for a regulator.

A number of cuneiform texts supplement and confirm that the excavated 'construction énigmatique' at Girsu was a regulator. It should be noted that regulators in cuneiform texts are often mistranslated as weirs or dams.

4. T. Jacobsen, "The waters of Ur", *Iraq* 22, 1960, 174-185.
5. M.-T. Barrelet, "Une 'construction énigmatique' à Tello", *Iraq* 27, 1965, 100-118.
6. W. Pemberton *et al.*, "Canals and bunds, ancient and modern", *BSA* 4 (1988) 207-221.
7. T. Jacobsen, "A Survey of the Girsu (Telloh) Region", *Sumer* 25, 1969, 109.
8. A. Parrot, *Tello*, p. 213, fig. 45.
9. J. Nougayrol, "Textes et documents figurés", *RA* 41, 1947, 23-24.

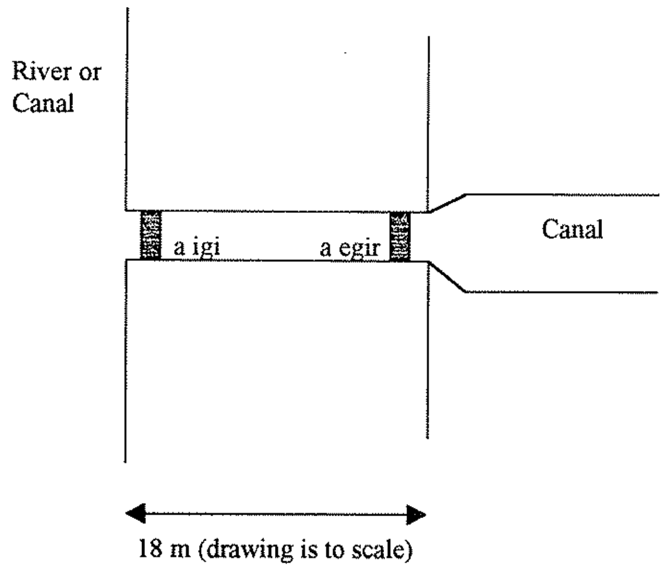


Figure 2

The Pre-Sargonic Lagash text *DP* 654 is described by Steinkeller.[10] In this a canal system of unrecorded length incorporated three nag-kud's. The first part of the text describes a length of canal that is in the process of construction or repair. The final part is a description of a regulator, called Kimah, that feeds water into the canal from a river at Ù-tir ("Forest Bridge"). The dimensions of the regulator are given (see *Figure 2*). The water channel (sluice) is described as 3 m wide and 18 m long with two structures 27 m and 24 m wide (long?) which protect the sluice as it cuts through the riverbank (levee). The water feeds into a canal system 6 m wide. These dimensions are similar to those of the regulator at Girsu and leave no doubt as to their purpose, although the canal that the regulator serves is narrower.

The use of baked brick and bitumen is confirmed in texts as well as in the archaeological excavation at Girsu. The inscriptional evidence of Eanatum Boulder A refers to a brick regulator on the Lumagimdu canal at Lagash which used 2,592 hl of bitumen. Enmetena rebuilt this regulator with 648,0000 fired bricks and 2,649.6 hl of bitumen. Another regulator was built by Uru-inimgina, King of Lagash, with 432,000 fired bricks and 2,649.6 hl of bitumen.[11] These two regulators would have been larger than the Girsu regulator, which contained an estimated 68,500 bricks.[12]

The earliest constructions of baked brick bonded with bitumen have been found in archaeological sites dated to the Uruk/Jemdet Nasr period (3200 - 2900 BC).[13] Which indicates that the materials needed for regulator building were available at an early date.

The use of reeds as foundations for irrigation constructions are also referred to in mathematical texts from the Ur III period.[14]

10. P. Steinkeller, "Notes on the irrigation system in third millennium Southern Babylonia", *BSA* 4, 1988, 73-92.
11. J. S. Cooper, *Sumerian and Akkadian Royal Inscriptions, I:Presargonic Inscriptions.* New Haven 1986, la.3.5, la.5.26, la.9.8.
12. J. N. Postgate, *Early Mesopotamia*, London & New York 1994, pp. 177-178.
13. M. Sauvage, *La Brique et sa mise en oeuvre en Mésopotamie*, Paris 1998, p. 112.
14. E. Robson, *Oxford Editions of Cuneiform Texts*, 14, Oxford 1999, p. 102: "6.4. Reeds and dams".

The "Lu-igisa archive" of tablets from Larsa cover the period from Abisare 7 to Sumuel (1898 - 77 B.C.) and has been interpreted by Walter.[15] A number of the texts describe the building of a regulator (kun-zi-da) at the junction of the Isin canal and the Euphrates. 1.3 million bricks were used in the construction of the regulator and associated works in Sumuel 14 (1881 B.C.). Beams were imported for the construction from Akšak (Opis) on the Tigris, suitable wood could have been floated down river from the Zagros mountains or from Assyria. The work was done during months 6 and 7 when the river level would have been at its lowest.

The Operation of Regulators

The volume of water passing through a regulator would have been controlled by removable horizontal wooden beams, which were placed at the intake end of the channel. There was no indication in the excavation report of grooves in the brickwork that held the ends of the beams in place, and the supports were probably made of wood and have decayed.

The height of the wall of beams could be added to, or reduced, as the river level rose and fell so controlling the volume of water entering the irrigation canal. It was important that the canal below the regulator contained a constant volume and rate of flow of water, since too much would flood over the canal banks and too little would reduce the water available for irrigation.

Evidence that a wall of horizontal removable wooden beams was used for the control of water flow is contained in the Epic of Gilgamesh. The translation of *tarkullātum, tarkullum* and *tarkulli* as weir-beams and their loss during the flood point to them as the essential components controlling the water flow through regulators.[16]

Steinkeller[17] and Maeda[18] quote *DP* 654 iv, 1, 2, 3, and v 1,2 and both suggest that the Ù-tir is situated next to or adjacent to the Kimah regulator (durun (TUŠ.TUŠ)). Ù is possibly 'bridge'; whether Ù-tir is a kind of bridge is unclear. Perhaps connecting the two halves of the regulator? As an essential part of the irrigation system the wooden parts would need regular maintenance.

The width of the regulator sluice would have been limited by the width that could be spanned by timber beams. The lengths of timber beams are rarely quoted in texts but spans greater than 5m would hardly have been practical.

The text *DP* 654 resolves a technical problem inherent in the design of the regulator at Girsu. The water entering the channel passes over the wooden wall and would fall, as much as 4 m, onto the floor of the channel, at a maximum rate of about 10 tons per second. This would cause damage to the brickwork notwithstanding the massive supporting piers. The modern solution to this problem is a 'stilling well' i.e. the creation of a well of water that the incoming water falls into so that the pressure is distributed equally to the sides and floor of the channel. A second wall of wooden beams at the exit of the channel would serve this purpose and was provided in this regulator. The first wall being the a igi and the second the a egir of the Kimah regulator in text *DP* 654.

15. S. D. Walters, *Water for Larsa*, Yale 1970, pp. 125-138.

16. See J.-R. Kupper, "L'irrigation a Mari", *BSA* 4 (1988) 99; A.L. Oppenheim, "Mesopotamian Mythology, II", *Or* 17, 1948, 53-54. See also Gilgamesh XI: 101-2: S. Dalley, *Myths from Mesopotamia*. Oxford 1989, p. 110; A. George, *The Epic of Gilgamesh*, London 1998, p. 91; N. K. Sanders, *The Epic of Gilgamesh*, London 1972, p. 112.

17. P. Steinkeller, *BSA* 4, 1988, 73-92.

18. T. Maeda, "Work Concerning Irrigation Canals in Pre-Sargonic Lagash", *ASJ* 6, 1984, 33-53.

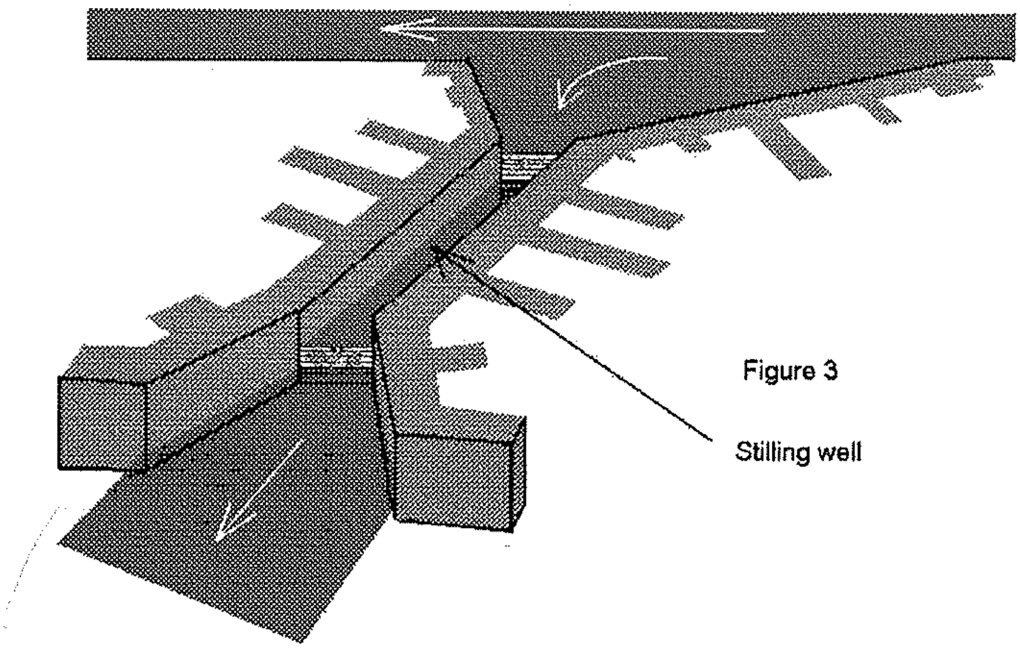


Figure 3

(describes the direction of flow of water through the regulator at Girsu, illustrating the position of the stilling well).

A Middle Babylonian text BE 17,12:4.18 mentioned by Steinkeller[19] describes a regulator *natbaktu* which has two weirs (*meḫru)*. The *pī natbakti* at the mouth of the regulator controlled the water flowing into the sluice and the *šēpīt natbakti* below this which formed a 'stilling well'.

The text IM 5592/6 from Umma[20] is a record of the rise of water level measured twice a day over a period of eleven days at an unknown site near Umma. The rise of water during the flood period is gradual and increasing since variations in rainfall and snow melt occurring in the headwaters of the Euphrates are evened out during the 2,750 km of river flow. A twice a day record was needed to establish by how much the wooden wall had to be raised to maintain a reasonably constant level of water in the irrigation canal. These records would have had to be taken at each regulator. The text IM 5592/6 records a rapid rise in water level, 189.75 cm in 11 days. This might have reached dangerous levels when flooding could have occurred and was possibly kept as a record of this exceptional event.

19. P. Steinkeller, *BSA* 4, 1988, 73-92.
20. P. Steinkeller, *ibid.*

It is interesting to note that soldiers were needed to guard the construction work of the regulator on the Isin canal,[21] the first indication of the political and strategic importance of regulators in Sumer. He who controlled the regulator controlled the irrigation potential of a very large area of land.

The Irrigation Potential and Distribution of Regulators

The width of the Girsu canal, inferred from the excavated fan was 16 m and the Kimah canal is given as 6 m in the text *DP* 654. This enables the area of land watered by the regulators to be calculated. The width, depth and gradient of a canal determine the volume of water flow it can carry. Only the width is known in these two cases but on the following assumptions:

1. Modern canal sizes.[22]
2. A four month irrigation period during the flood (months XII, I, II, III).
3. A cereal crop water requirement of 600 mm (600 l/m^2) per year.
4. A 40% loss of water due to evaporation and seepage in the distribution system.

It can be calculated that the area of irrigated land watered by the Girsu and Kimah regulators was in the order of 10,000 ha and 2,000 ha respectively. As the arable system was based on alternate cropping and fallow years the total area of cultivated land would have been 20,000 ha and 4,000 ha respectively.

The attached map (*Figure 4*), originally produced by Jacobsen[23] following his Survey of the Girsu Region, has been modified to show the widespread distribution in Sumer of the regulators mentioned in this paper: Umma, Girsu, Lagash, Shurruppak, Larsa and Isin.

Concluding Remarks

The earliest reference in this analysis of regulator design and use is in the early third millennium text of the Epic of Gilgamesh. Wooden beams displaced in the flood are interpreted as being part of a regulator, variously translated as 'dykes and weirs'. The earliest flood texts date to the early third millennium, about the same time as baked brick and bitumen buildings have been found. However, smaller wooden regulators could have been used, although they would not have been deep enough to be used during the whole period of the flood. Irrigating the land for only a short period at the height of the flood could have produced sufficient irrigated land for smaller communities.

The 'construction énigmatique' (2150 B.C.) is a very sophisticated design, which is difficult to improve upon, and was clearly the product of, a long period of experience in regulator building. The Lagash regulators of Eanatum (2400 B.C.) and Uru-inimgina (2350 B.C.) were of an earlier date and larger, and used more bricks. The latest regulator considered, that built by Sumuel at the head of the Isin canal was built in 1881 B.C.

A regulator fed a canal with water that flowed during the flood period. The Girsu regulator fed a canal some 16 m wide. This was probably too wide for divisors (káb-kud's) to work efficiently,[24] káb-

21. S.D. Walters, *Water for Larsa*, p. 162.
22. W. Pemberton *et al.*, *BSA* 4, 1988, 207-221.
23. T. Jacobsen, "The Girsu Region", *Sumer* 25, 1969, 109.
24. R. Dight, "Re *appum* and káb-kud", *NABU* 1998:3.

kud's of this width are not indicated in Ur III texts. Water was probably diverted off the canal by other regulators to feed separate agricultural areas. The absence of káb-kud's in the canal would have made it suitable for traffic by large boats, but only in the flood season.

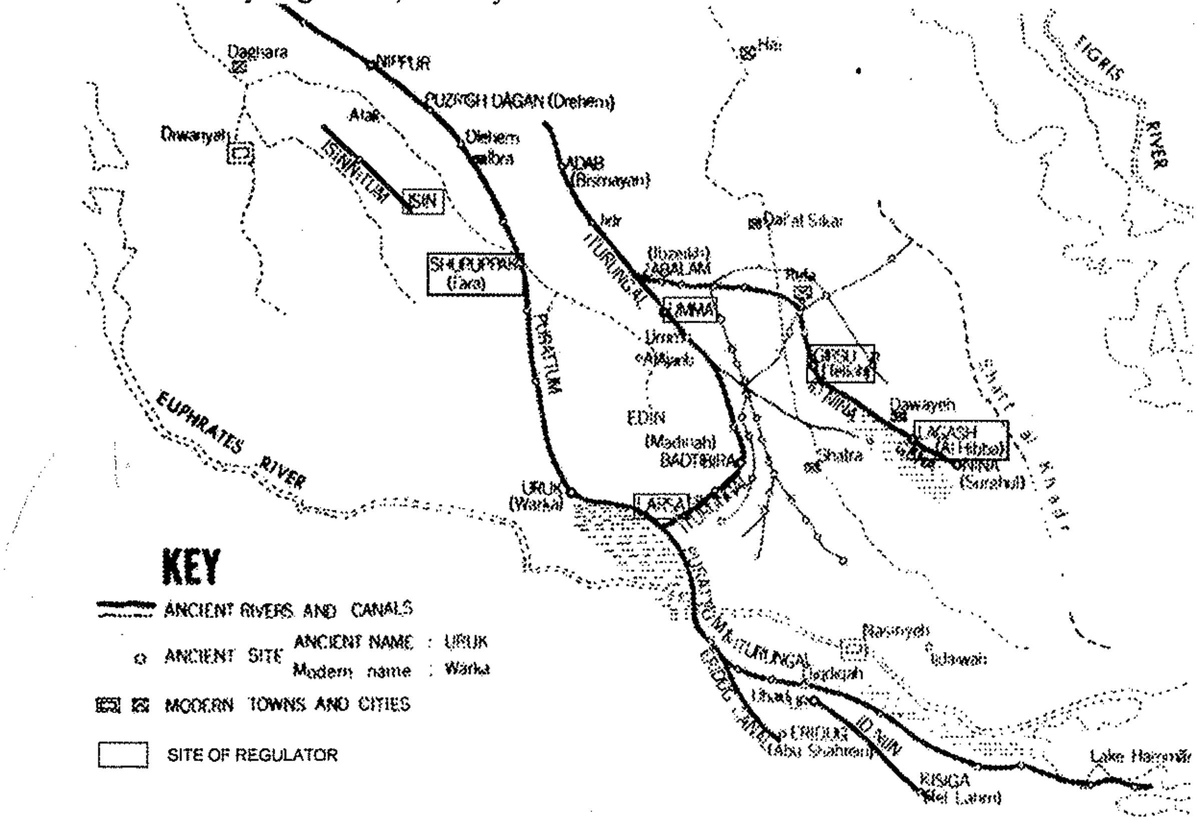


Figure 4

The water from the Kimah regulator canal, of 6 m width, was divided into four smaller channels by three divisors (káb-kud's). This was clearly an agricultural irrigation system. These channels only contained water during the flood period and would be dry and in a suitable condition for silt clearance and other maintenance work during the dry months.

The large size of regulators and the area of land they were capable of irrigating suggest they could have been built only by wealthy cities, controlled by either kings or religious institutions. The Larsa archive indicates the strategic importance of the regulator for controlling large tracts of agricultural land and its population.