Pergamon

Wat. Sci. Tech. Vol. 40, No. 4–5, pp. 43–50, 1999

0273–1223/99 $20.00 + 0.00

PII: S0273-1223(99)00484-9

WASTEWATER REUSE FOR RIVER RECOVERY IN SEMI-ARID ISRAEL

Marcelo Juanico and Eran Friedler

Juanico & Friedler Mediterranean Ltd, Sewage Treatment, Storage & Reuse, Process Design Consulting and Catchment Basin Management & Monitoring for Water Quality, Ram-On, 19205 M. P. Megido, Israel

ABSTRACT

Most of the water has been captured in the rivers of Israel and they have turned into dry river-beds which deliver only sporadic winter floods. In a semi-arid country where literally every drop of water is used, reclaimed wastewater is the most feasible water source for river recovery. Two topics are addressed in this paper: water quality management in rivers where most of the flowing water is treated wastewater, and the allocations of reclaimed wastewater required for the recovery of rivers and streams. Water quality management must consider that the main source of water to the river has a pollution loading which reduces its capability to absorb other pollution impacts. The allocation of treated wastewater for the revival of rivers may not affect negatively the water balance of the region; it may eventually improve it. An upstream *bruto* allocation of 122 MCM/year of wastewater for the recovery of 14 rivers in Israel may favor downstream reuse of this wastewater, resulting in a small *neto* allocation and in an increase of the water resources available to the country. The discharge of effluents upstream to revive the river followed by their re-capture downstream for irrigation, implies a further stage in the intensification of water reuse.

KEYWORDS

Mediterranean; river recovery; water allocations; water quality; water reuse.

INTRODUCTION

In the past, relatively large quantities of water flowed in the few rivers and some of the 'nahalim' or 'wadies' of Israel (streams which run dry or almost dry during the Mediterranean summer, while flowing during the rainy winter). The 'natural' base-flow (excluding winter floods) of the rivers amounted to about 300-400 MCM/year, while the Jordan river alone added several more MCM/year. Since the beginning of the 20th century, as a consequence of population growth and the resultant increase in water demand, most of the flowing water was captured at source and diverted to meet the growing needs for water supply. Thus, most rivers and streams turned into dry river-beds which deliver only sporadic floods during the winter. Simultaneously, the same accelerating population growth resulted in uncontrolled discharge of raw sewage into the rivers, transforming many of them into open sewage channels. In recent years, various organizations (governmental and non-governmental) invested increasing efforts to improve the poor condition of the rivers and streams in the country. These efforts resulted in the creation of 'The Administration for the Recovery of Israeli Rivers', and in an official recognition of rivers and streams as 'legitimate water users'.

In a semi-arid country such as Israel where literally every drop of water is used, reclaimed wastewater is the most feasible water source for river recovery (Gafni and Bar-Or, 1995). Indeed, 'The Administration for the

Recovery of Israeli Rivers' already initiated some projects where reclaimed wastewater serves as the main water source for the recovery of rivers and streams (Friedler and Juanico, 1995, 1996, 1997).

Two main topics concerning the use of reclaimed wastewater for the recovery of rivers and streams are addressed in the present paper:

1. Water quality management in rivers where most of the flowing water is treated wastewater.
2. Water allocations (or reclaimed wastewater allocations) required for the recovery of rivers and streams, and their meaning within the framework of water resources management.

WATER QUALITY MANAGEMENT

Water quality control in rivers fed almost exclusively with treated wastewater must take into consideration that the main source of water to the river has a pollution loading which reduces the capability of the river to absorb further pollution impacts. Water quality must match the requirements for the development of healthy flora and fauna, and for human activities which include sporadic contact with river water. Swimming in the rivers has not been defined as an immediate desired goal.

The management of water quality under the given conditions (main water source is reclaimed effluent) must find a balance between two different approaches:

1. Controlling the quality of the wastewater discharged to the river.
2. Controlling the quality of the water running within the river.

Controlling the quality of the wastewater discharged to the river

This approach concentrates the water quality control effort on the allocated wastewater. The pollution loading of the allocated reclaimed wastewater must be reduced as much as possible. This approach may be favored in rivers that receive only or almost only treated wastewater.

A review of the few data and information available on the behavior of the rivers and streams of the Mediterranean Sea Basin and other semi-arid regions (Aboal *et al.*, 1994; Bowden and Young, 1984; Dobbs and Zabel, 1996; MacKay *et al.*, 1995; Takahashi, 1991; The Nature Reserves Agency field data from Israel rivers) allowed recommendation of the following tentative limiting values to a series of parameters of the effluents allocated to the river (Table 1). Discharge of effluents matching these values are not likely to cause oxygen depletion due to degradation of organic matter, excessive eutrophication due to nutrients supply, or ammonia intoxication.

Table 1. Maximum values proposed for effluents discharged into rivers and streams under the summer conditions in Israel. See footnotes 1 to 6

Parameter	'Turbulent' streams (or parts of them) (slope > 5 ‰)	'Non-turbulent' streams (or parts of them) (slope < 5‰)
BOD_5 (carbonaceous)	10 mg/l	5 mg/l
P total	0.5 mg/l	0.1 mg/l
NH_4-N	3 mg/l	1 mg/l
Faecal coliforms	Geom. mean ≤ 200/100 ml	Geom. mean ≤ 200/100 ml
Residual Chlorine	≤ 0.1 mg/l	≤ 0.1 mg/l

1. These values do not ensure that the river will match a desirable river quality objective, because the river may have other sources of pollution supplying BOD, P and NH_4.
2. Even if BOD, P and NH_4 are maintained below these values within the river, this will not ensure a desirable river quality objective, because other substances besides the ones included in the table may negatively affect the water quality within the river (e.g., detergents, phenols, pesticides, salts, heavy metals, residual chlorine, etc.).

3. These values are set for rivers with effluents as the single source of water. When the discharged effluents are diluted within the river in water of better quality from other sources, the values can be increased by the dilution factor.
4. These values assume that the self-purification capacity of the river is not considered and that the desired quality must be accomplished from the point of effluent discharge. However, the river manager should take into account that the effluents may be discharged with a BOD=10 mg/l in the upper part of a river with a slope > 5‰ but (due to self-purification processes) the BOD may drop to < 5 mg/l when the effluents reach the lower part of the river with a slope < 5‰ (a reduction in P total and NH_4 may be also expected).
5. These values refer to summer conditions. They can be doubled during the winter (December to February inclusive) due to the lower temperatures which slow down BOD decomposition and resulting oxygen uptake, and to lower solar radiation which limits algae growth and eutrophication problems. Besides, effluents are diluted in flooding waters during the rainy winter of the Mediterranean. The policy of 'winter relaxation' may be important, because sewage treatment plants may have problems to match the requested values during the low temperatures of the winter which affect the biological processes of the plant.
6. A 'N total' limit is not recommended. Nitrogen acting as a limiting factor of eutrophication favors the development of Cyanophyta (blue-green algae) which can fix N from the atmosphere; some of these algae may cause severe nuisances and intoxication of the aquatic biota. The NH_4 limit is due to the toxic potential of this compound at high pH values, and not to its effect as a nutrient. However, in streams with significant seepage a 'N total' limit may be necessary in order to protect the aquifer.

Controlling the quality of the water running within the river

This approach defines the quality of the water running within the river and spreads the water quality control effort among the allocated wastewater and the other sources of pollution. If the quality requirement for the wastewater allocated to the river is too strict, it may sharply increase the treatment costs while having an inconspicuous effect on the quality of the water running within the river, due to the contribution of other sources of pollution. A more holistic approach extending quality management to the whole catchment area may render better results. This approach has been adopted in several countries (Behrendt, 1994; Ellis and House, 1994; Ferguson, 1991; Metthews, 1995; Popel, 1995; Rees and White, 1993; Smith, 1990). It may be favored in rivers that receive other sources of water and pollution besides the treated wastewater:

- agricultural drainage and run-off.
- urban and roads run-off.
- other sources of point-source pollution, such as illegal continuous discharges or sporadic accidental discharges.

The quality of the water running within the river can be defined in conceptual terms rather than a set of values for a set of parameters (Table 2).

WATER ALLOCATIONS

The hydrological regime

The hydrological regime of most rivers and streams in the Mediterranean coast of Israel is characterized by:

- Strong sporadic flooding waters during the 3-4 winter months, followed by a modest base-flow during the dry summer. Some streams are totally dry during the summer.
- The base-flow -when it exists- represents a small percentage of the total annual volume of water running down the river (there are few exceptions to this rule).
- Most rivers show huge differences in flow between years, both in the total annual volume of water and in its distribution during the winter months.

- Due to the irregularity of rains and consequent winter floods, the most conspicuous role of floods is to maintain the channel open and clean. This is specially important in arid regions where streams with dams that completely catch the floods may eventually fill up and vanish. Besides, flood pulse regimes are also important for the recovery and maintenance of the particular biota of arid streams (Por, 1981; Fisher *et al.*, 1982; Giudicelli *et al.*, 1985; Bailey, 1991; Gagneur, 1994).
- Small springs may provide minor amounts of water to the river and produce a wet sector of few hundred metres. However, due to the constant flow during most of the year, they allow the development of a particular biota which may contain endemic species. The small springs become refugees for reduced and endangered species of animals and plants which may not survive in treated effluents even if these are of very good quality.
- There exists a layer of clay in the bottom of most rivers, which obstructs the infiltration of river water to the aquifer. This point must be considered when feeding the river with treated wastewater.

Table 2. Definition of the quality of the water within the river in conceptual terms

Issue	Desired effect	Required standard
visual pollution	clean river	no garbage discharge
	water surface without foam	low concentration of detergents and dissolved organic matter
public health	river water will not be vector of diseases	swimming water bacterial standard
dissolved oxygen	• concentration always positive • no negative effects on flora and fauna	low COD and BOD low trophic level, low P level
flora and fauna protection	original salinity	electrical conductivity similar to the original one
	toxicity that does no affect flora and fauna	low concentration of: • Ammonia • biocides • solvents • heavy metals • hard detergents • residual Chlorine • other low general toxicity (toxicity tests and/or bioassays)

Different kinds of water allocations

A request for allocation of water may be based on three different reasons, according to the planned uses of the river:

1. Ecological needs - Water allocation needed to restore part of the ecosystem which characterized the river in the past, and to enable the development of a diverse and healthy aquatic community.
2. Landscape development needs - Water allocation needed to develop the river and the surrounding area to parks and 'green belts' which are most important in a small densely populated country with large urban areas.
3. Economic activity needs - Water allocation needed to enable commercial development relying on the river as a focal point (restaurants, hotels, commercial sport centers, etc.).

The cost of each kind of water allocation may be funded by different sources: while ecological recovery of the river may be defined as a national goal funded by the central government, the development of parks may be defined as a local interest funded by the local government, and water allocations to allow economic activities such as a recreational commercial center may be funded by private entrepreneurs.

The difference between the *bruto* and *neto* allocations must be stressed:

- The *bruto* allocation is the amount of reclaimed wastewater which must be discharged into the river in order to fulfill the flow requirements for the different needs.
- The *neto* allocation is the *bruto* one minus the amount of water which can be taken from the river downstream and reused for other purposes (e.g., agricultural irrigation, irrigation of parks on the river banks, groundwater recharge, etc.).

Calculation of the required water allocations for base-flow

Water allocation for ecological recovery. The 'natural' historical flow of each river was calculated based on data from the Israeli Hydrological Service. Old data were taken from the reports of the previous British Administration:

1. Annual volumes were plotted by year; the years before human intervention were selected for further analysis.
2. For the selected years, summer monthly flows were plotted and the 'natural' monthly summer flow calculated. This was considered as the 'natural-base-flow' of the river.
3. Where data were available, comparison of hydrological stations in different parts of the river and spring flow measurements allowed us to calculate the 'natural-base-flow' in more detail.

Two values were assigned to the *bruto* allocation for ecological needs, based on a review of the experience gained in other parts of the world especially in those with characteristics somehow similar to Israel (e.g., Australia: Arthington, 1994, and Italy: Bagnati *et al.*, 1994):

1. 30% of the 'natural' base-flow of a river was defined as the minimum average flow required to maintain a stable ecological community.
2. 10% of the 'natural' base-flow of the river was defined as the minimum survival flow which guarantees that the ecological community will not disappear if this flow is maintained for a limited period. The maintenance of the survival flow during long periods would put the ecological community in danger.

It should be noted that the average flow is a mean value and the instantaneous flow in the river may vary up and down. On the contrary, the survival flow is an instantaneous value which can not be reduced in any circumstance without seriously affecting the ecological community.

Other methodologies to calculate water allocations for ecological needs such as 'wet perimeter', 'habitat simulation' and 'river modelling' were discharged due to lack of data, time and budget.

Water allocations for landscape development and economic activities. The amounts of water required for these purposes were calculated by means of the 'Manning function', based on a definition of the width and depth of the desired water body, plus data on the slope of the river (Baird and Achterberg, 1989). The calculation of the amount of water required to obtain a given river width, depth and water velocity was made in accordance with the desired scenic result (Brown and Daniel, 1991; Duffield *et al.*, 1992).

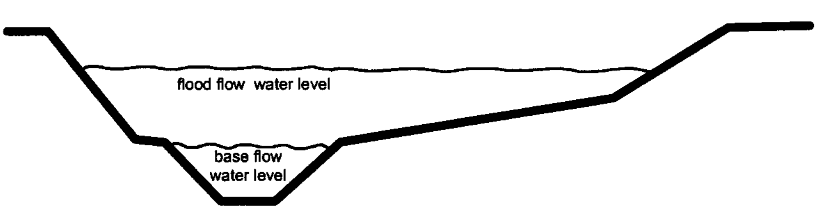

Figure 1. Schematic representation of a double channel profile.

In some cases, the amount of water required for the recovery of a specific river was much more than the available sources in the region. A too small water allocation will then result in a large channel (required to contain the winter floods) which will run too shallow water during the summer months. In this case, it was recommended to switch to a 'double channel' profile as represented in Fig. 1.

The water allocations required for 14 selected rivers in Israel

A study of the allocation needs for the recovery of 14 main rivers and streams in Israel (Friedler and Juanico, 1996) revealed that some 122 MCM/year of reclaimed wastewater may be required, a frightening volume in a country with very limited water resources. But, the study also revealed that this amount of water is already running in the rivers, generally as raw sewage or low quality wastewater. The problem is that this flow has inappropriate quality, it enters the rivers at inappropriate places, and it is running in an inappropriate time of the year. The formal allocation of this wastewater to the rivers will make possible the investments in treatment and storage required for the release of wastewater of proper quality in proper places and time. And the implementation of this step will allow the reuse of the allocated wastewater downstream, a thing which is impossible today. Thus, surprisingly, the *bruto* allocation of 122 MCM/year of wastewater for the recovery of rivers may result in a small *neto* allocation and in an increase of the water resources available to the country.

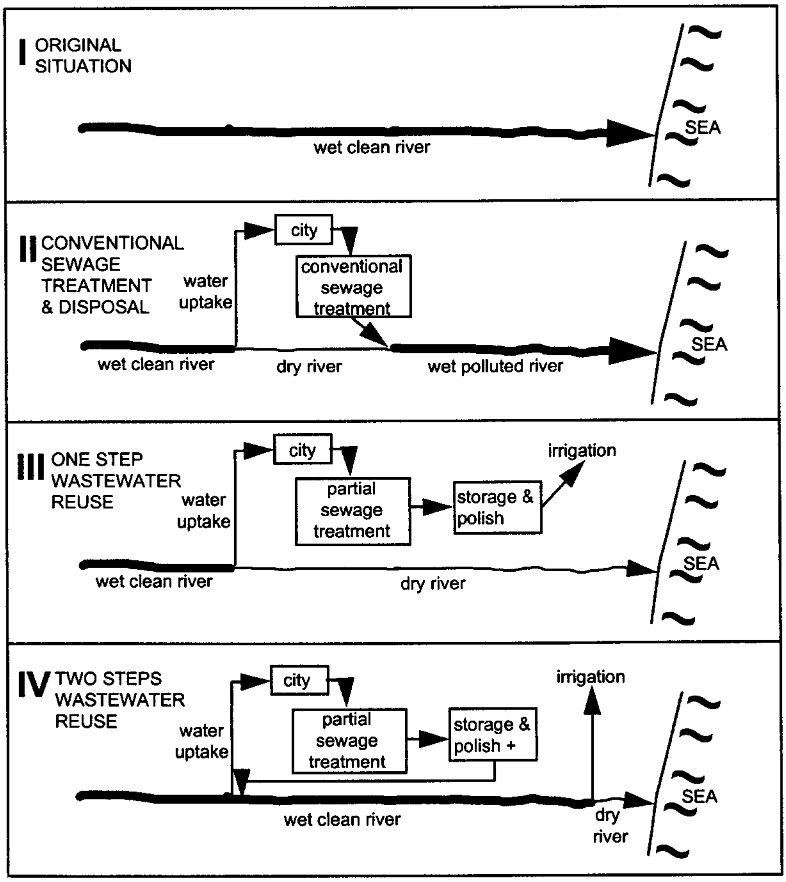

Figure 2. Four historical stages in the development of the water reuse and river recovery concept.

The discharge of treated effluents upstream in order to revive the river, and the re-capture downstream before the discharge to sea in order to derive them for irrigation and other purposes, implies a further stage in the intensification of water reuse (Fig. 2).

CONCLUSIONS

Wastewater effluents may be the main or even single available source of water for the recovery of dried rivers in arid and semi-arid countries suffering water shortage.

Water quality control in rivers fed almost exclusively with treated wastewater must take into consideration that the main source of water to the river has a pollution loading which reduces the capability of the river to absorb further pollution impacts.

The allocation of treated wastewater for the revival of rivers, even in large amounts, does not necessary affect negatively the water balance of the region; it may eventually improve it.

The discharge of treated effluents upstream in order to revive the river, and the re-capture downstream before the discharge to sea in order to derive them for irrigation and other purposes, implies a further stage in the intensification of water reuse.

REFERENCES

Aboal, M., Puig, M., Sanchez, A. and Soler, G. (1994). Algal standing-crop in some Mediterranean temporary rivers in Southern Spain. *Verh. Internat. Verein. Limnol.*, **25**, 1746-1750.

Arthington, A. H. (1994). A holistic approach to water allocation to maintain the environmental values of Australian streams and rivers: A case history. *Mitt. Inernat. Verein. Limnol.*, **24**, 165-177.

Bagnati, T., Parini, S. and Saccardo, I. (1994). A model for the assessment of minimum instream flow in Italian scenarios. In: *Integrated river basin development*, C. Kirby and W. White (eds). John Wiley & Sons, pp. 153-164.

Bailey, P. (1991). The flood pulse advantage and the restoration of river-floodplain systems. *Regulated rivers: R&D* **6**, 75-88.

Baird, D. and Achterberg, D. (1989). Estimating velocity and scour in river bends. In: *Sediment transport modelling*, S. Wang (ed). ASCE, pp. 462-467.

Behrendt, H. (1994). Point and diffuse load of pollutants in the Rhine River basin. *Verh. Internat. Verein. Limnol.*, **25**, 1922-1925.

Bowden, K. and Young, D. (1984). River quality and sewage effluent standards. *J. Inst. Water Eng. & Sci.*, **38**(6), 511-527.

Brown, T. and Daniel, T. (1991). Landscape aesthetics of riparian environments: relationship of flow quantity to scenic quality along a wild and scenic river. *Water Resour. Res.* **27**(8), 1787-1795.

Dobbs, A. and Zabel, T. (1996). Water Quality Control. In: *River Restoration*, G. Petts and P. Calow (eds). Blackwell Sci. Publish., pp. 44-59.

Duffield, J., Neher, C. and Brown, T. (1992). Recreation benefits of instream flow: application to Montana's Big Hole and Bitterroot rivers. *Water Resour. Res.*, **28**(9), 2169-2181.

Ellis, J. and House, M. (1994). Integrated design approaches for urban river corridor management. In: *Integrated river basin development*, C. Kirby & W. White (eds). John Wiley & Sons, pp. 311-323.

Ferguson, G. (1991). Urban Stream Reclamation. *J. Soil Water Conserv.*, **46**(5), 324-328.

Fisher, S., Gray, L., Grimm, N. and Busch, D. (1982). Temporal succession in a desert stream ecosystem following flash flooding. *Ecol. Monogr.* **52**(1), 93-110.

Friedler, E. and Juanico, M. (1995). Policy of water sources and quality management in the Alexander river. In: *Master Plan for the Recovery of the Alexander River*, A. Brandais. Report to the Adminstration for the Recovery of Israeli Rivers, pp. 104-133 and 271-279 (in Hebrew).

Frielder, E. and Juanico, M. (1996). *Water allocations for the recovery of selected rivers in Israel.* Report to the Adminstration for the Recovery of Israeli Rivers, 150 pp. (in Hebrew).

Friedler, E. and Juanico, M. (1997). *Master Plan for the Recovery of the Sorek River - Water quantity and quality.* Report to the Adminstration for the Recovery of Israeli Rivers, 65 pp. (in Hebrew).

Gafni, A. and Bar-Or, Y. (1995). Conceptual proposal for the use of the wastewater excedents for the revival of main rivers in Israel. *Water and Irrigation*, **345**, 45-48 (in Hebrew).

Gagneur, J. (1994). Flash floods and drying up as major disturbances upon benthic communities in North-African wadis. *Verh. Internat. Verein. Limnol.*, **25**, 1807-1811.

Giudicelli, J., Dakki, M. and Dia, A. (1985). Caracteristiques abiotiques et hydrobiologiques des eaux courantes mediterraneennes. *Verh. Internat. Verein. Limnol.*, **22**, 2094-2101.

MacKay, H., Roux, D., Ashton, P., Vliet, H. and Jooste, S. (1995). The development of South-African water quality guidelines for the natural aquatic environment. *Wat. Sci. Tech.*, **32**(5-6), 293-299.

Metthews, P. (1995). Water quality objectives: a tool to ensure environmental protection and wise expenditure. *Wat. Sci. Tech.*, **32**(5-6), 7-14.

Popel, H. (1995). Advanced wastewater treatment in Germany - effluent requirements, design standards, practical experience and problems. *Europ. Water Poll. Control*, **5**(4), 5-17.

Por, D. (1981). Streams in the desert - What they have in common? In: *Developments Arid Zone & Environ. Quality*, H. Shuval (ed), 409.

Rees, A. and White, K. (1993). Impact of combined sewer overflows on the water quality of an urban watercourse. *Regulated Rivers: Res. & Manag.*, **8**, 83-94.

Schutze, M., Butler, D. and Beck, M. (1996). Development of a framework for the optimization of runoff, treatment and receiving waters. *7th International Conference on Urban Storm Drainage*, Preprints 6 pp.

Smith, D. (1990). A better Water Quality indexing System for Rivers and Streams. *Water Res.*, **24**(10), 1237-1244

Takahashi, M. (1991). Guidelines for environmental enhancement in Japan. *Wat. Sci. Tech.*, **24**(9), 133-142.