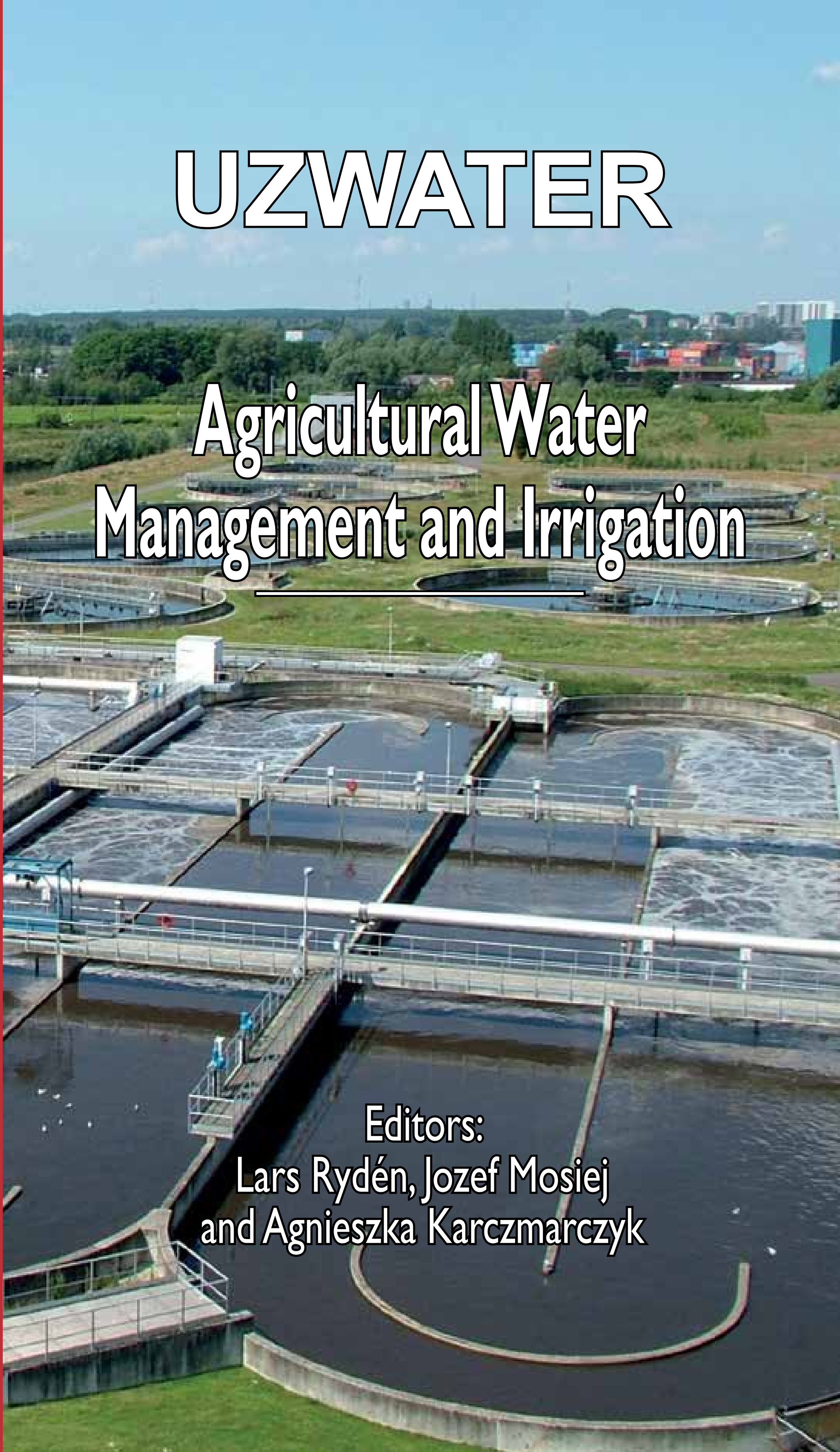

UZWATER

Agricultural Water Management and Irrigation

Editors:
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and Agnieszka Karczmarczyk

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Cover Photo: Overview of the wastewater treatment plant of Antwerpen-Zuid, located in the south of the agglomeration of Antwerp (Belgium). Photographer: Annabel

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Content Overview

Content

Chapter 1
Improving the Land – Past, Present and Future

1.1 History of land improvement

Land amelioration is a system of measures aimed at raising soil fertility. It ensures the efficient agricultural use of bogs, waterlogged soils, scorched deserts, semi-deserts, and lands degraded under irrational anthropogenic loads. It is one of the most important means for sustainable production of food and industrial raw materials. Over the history of human development, considerable experience has been gained in the field of land amelioration, and a separate branch of applied science – amelioration science – has been developed. The science and practice of amelioration are based on the achievements of fundamental sciences such as physics, mathematics, chemistry, and biology. At present land amelioration is performed in virtually all countries of the world, and it is essential for the food and ecological security of individual countries and the world community. Current demographic growth and industrial development have created a grave problem of competition in the use of water and land resources and water quality preservation.

Agenda 21 of the UN Conference on Environment and Development (UNCED) held in Rio de Janeiro in June 1992 orients the world community toward the involvement of all interested parties at all levels, including water consumers, designers, managers, and politicians, because water is of economic value for all competitive forms of usage. The multipurpose approach, and ecological, social, and economic principles of land amelioration should provide the basis for new systems of land and water management to enable the sustainable development of modern civilization.

Amelioration the improvement of agricultural land for obtaining high and steady crop yields became a human profession at the time this word appeared, to denote work on land improvement. The assimilation of new lands for agricultural production and the expansion of agricultural areas started at the very beginning of ancient agriculture. The notion of land amelioration formalized a definite sequence of operations for increasing crop yields. Land irrigation systems in the droughty regions of ancient Egypt, Mesopotamia, India, China, and some other parts of the world can be considered the first historical monuments of land amelioration. At present, the term “amelioration” (improvement) has the most general meaning. The particular kinds of land amelioration are: land irrigation and drainage, assimilation of new lands, slope terracing, flood and erosion control measures, land sanitation, rehabilitation of degraded and polluted soils, reclamation of low-productive soils, and the application of fertilizers, soil amendments, and conditioners.

The history of land amelioration reflects the progressive development of productive forces, scientific achievements, and practices in different countries. An analysis of the history of amelioration is important for evaluating modern attitudes about the subject and developing optimal lines of inquiry for the future.

1.2 Land amelioration in the ancient world

Primitive gatherers and hunters led a nomadic life. The Neolithic revolution, marked by the domestication of wild animals and plant species and the appearance of primitive stone tools for use on cultivated land, made it possible for people to organize permanent settlements. The first permanent settlements of ancient farmers were along rivers. Periodically flooded lands had better moisture and were fertilized by the silt brought by floodwater, and this permitted high yields without any artificial measures. As the human population increased, the lack of free space on flood plains forced people to cultivate the less fertile land deprived of vivifying floods. Under these unfavourable conditions humans tended to replace the effect of natural floods by artificial measures, and as a result irrigation was invented. Irrigation rapidly extended over the land where drought ensured that wild plants and crops perished. Artificial canals and basins for water accumulation crossed the newly assimilated land and supplied it with water.

Some tribes went to the north in the search of new lands. In the severe northern environment, they found vast forests and bogs with isolated areas under meadows. The lea tillage enabled the first migrants to live, but the soils gradually lost their fertility and became sterile, especially during drought years. With the growth in population, the need for agricultural land increased, and the soils under forests and bogs were developed. Two amelioration practices (irrigation and flooding) were supplemented by drainage and deforestation. The use of fire for the development of forested lands ensured the additional fertilization of soil with ash, which increased the crop yield. Thus, a system of "slash and burn" agriculture was established in forested areas.

The development of human civilization is inseparable from the development of land amelioration. In fact, the need to ameliorate lands was one of the main driving forces of the development of human societies. Historians note that the first states with permanent settlements (towns) encircled by agricultural areas appeared about 4,000 BC in the fertile flood plains of the Nile, Tigris, Euphrates, Yangtze, Huang He, and central Indus, as well as in the Syrian and Iranian foothills.

The labour-consuming drainage of waterlogged land by means of canals, land irrigation, and construction of water-collecting basins "not only accelerated the union of tribes, but also developed their material and spiritual cultures," as Bunin puts it (Bunin, 1979).

The lower Nile basin was populated as far back as the Paleolithic period. Work on the protection of croplands from floods, drainage of waterlogged territories, and artificial delivery of Nile water to the territories lying far from the river, initiated the early formation of territorial communities. The latter formed the basis for the politically independent regions (nomes) that were consolidated under the supreme power of the Pharaoh in the end of the fourth millennium BC. The Nile played an essential role in the life of the ancient Egypt. It irrigated the flood plain during the high-water period in the fall; the precipitated river drifts sustained soil fertility; the Nile was also the single throughway. Therefore, Egyptians made a cult of the Nile at the earliest stage of the civilization. From the evidence of Herodotus and Plutarch, they called irrigation the marriage of the Nile with the Earth: "Osiridis cum Nephti coitum." Ancient Egyptians idolized any manifestation of soil fertility.

To protect their settlements from high Nile floods, special engineering measures were performed. These measures included the preparation of the territory for the construction of temples and palaces, the diking of towns, the construction of dams and water-collecting basins, irrigation, and drainage. These works were supported by the state. Their scale was really impressive: the remains of a 12 m high and 100 m long ancient dam date back to 5,000 years ago.

In ancient Rome, irrigation played an important role. Cato repeatedly mentioned the artificial irrigation in his treatise on agriculture and unequivocally noted irrigated land as the best estate. Virgil, Pliny, Columella, and others considered it necessary to irrigate grass lands along with ploughed areas. Pliny recommended starting irrigation after the spring equinox, ceasing it during the period of grass flowering, and recommencing it after haying. Many ruins of locks, canals, and water pipelines, dating from the Age of Emperors (between Augustan and Theodosius), can be found today and attest to the wide development of irrigation in ancient Rome. It should be noted that the Romans were well aware of the harm caused to crops by excessive moisture and moisture deficiency during periods of drought. They paid attention to the arrangement of canals to discharge excessive water after irrigation. Since then, drainage has been considered as a component of irrigation.

1.3 The first irrigation schemes

Irrigation was performed in Egypt (as well as in India and China) by flooding basins. This oldest irrigation method was perfected gradually. For flooding irrigation, the territory was divided by dikes into a network of terraces forming basins. The flood water was taken in the upper basin, passed through it, and entered the lower basin through a lock gate in the under dam. The basins were up to 150 km^2 in area. The moistening – fertilizing irrigation process was used.

Pliny presented examples of the extreme fertility of irrigated land: the soil fertility in the African sands near watersheds (Takan) increased to a miraculous level due to irrigation. The water was distributed between landlords according to schedule, and irrigation favoured a peculiar farming system: olives grew under high palms; fig trees grew under the olives; pomegranates grew under the fig trees; vineyards were located still lower, and wheat, vegetables, and fodder grasses were planted in turn between vineyards. The soil yielded fruits all the year round, and its fertility depended on the art of the land cultivators.

Egypt presented a great example of agricultural reclamation. According to Herodotus, so strong was the belief of the Romans in irrigation that when they learned that all land was not irrigated in ancient Greece they expressed their apprehension that all Greeks would die of famine in the case of drought. In Mesopotamia, irrigation began with the colonization of land, at the same time as in Egypt. An ardent heat to the south of Babylon lasted for nine months per year, and therefore irrigation was indispensable. The fertile loess soils gave abundant yields under irrigating conditions, date palm being the main culture.

About 6,000 years ago, dams on the Tigris and Euphrates rivers were constructed almost simultaneously with the dams on Nile and Yangtze. Irrigation was impossible without the water from these rivers. Water shortages did not limit the development of irrigation until the mid-nineteenth century. Large irrigation systems with water extraction from the Tigris were constructed between 2600 BC and 1400 BC. The first measures of soil salinization control by leaching and constructing drainage canals in the territory of modern Iraq date back to 2400 BC.

The development of irrigation systems in Mesopotamia and Egypt between 4000 BC and 2000 BC, and large-scale work on the construction of canals, outfalls, and flood (detention) pools stimulated the emergence of exact sciences and the flourishing of handicrafts. Distribution of water and construction of canals and hydraulic structures accelerated the evolution of engineering and geometry. The farmer needed an accurate calculation of time and this resulted in the development of the calendar. In this way the evolution of skill and experience in irrigation farming in the most ancient agricultural centres stimulated the evolution of science and the progress of society.

Israelites transferred the art of irrigation from Egypt to Palestine, where it also became an essential part of life. The Book of Genesis says that all Jordanian fields were irrigated by means of artificial water supply, as well as the Egyptian land. Water-engines were also known: for instance, Moses mentions a treadle water-lifting gear.

Very high yields were obtained because of irrigation: the yield of wheat was between 100 and 300 times as much as the amount of wheat seeds sown in Assyria, Egypt, and Syria. In ancient Greece, land was irrigated from springs and rivers; the irrigated land was highly prized, especially in Attica, where special irrigation legislation was put in force.

After the fall of the Roman Empire agriculture fell into decay around the world, and knowledge of irrigation practices remained only in some regions of Europe, mainly in the monasteries. From ancient history, the Pont du Gard, the aqueduct over the Tarn River in France constructed by Romans, should be mentioned.

1.4 Beginning of agriculture and the great floodplain systems

Between the sixth and third millennia B.C., the major valleys and foothills of three great rivers of Africa and Asia – the Nile, the Euphrates and the Indus – were developed for agriculture. Research by the Russian geographer and historian L.N. Gumilev, in connection with population increase, showed that the area of idle land favourable for agriculture in the foothills was shrinking at that time.

People left and moved farther afield, into the droughty steppes, or went to the plains, which were periodically inundated by floodwaters. In the arid zones and the hot dry steppes, grasses (family *Poacae*) could not grow without artificial irrigation.

Agriculture was very problematic, as all three of these major rivers frequently burst their banks, periodically inundating large areas, and often for months at a time. The crops were either often swamped by floods or burned by the sun after the flood receded. Hence, the harvests here were much poorer than in the favourable conditions of foothills, even though no sufficient nutritional input was provided.

Many centuries had to pass until the inhabitants of the great river valleys overcame the problems of rational management of floodwaters for agriculture. Depending on the local natural conditions, different methods were adopted. In the Nile valley, the floods began in June and the water stayed until October. Waters were held back on the fields by earth banks (in modern terminology, it was a sort of firth irrigation and water retention system). Water was collected within embankments, and a prolific silt precipitated, after which the water was drained, and the silt left behind retained sufficient moisture for the whole period of grain crop cultivation. Furthermore, the silt itself was a perfect fertilizer. This was probably the first example of a combined water and fertilizer management system on reclaimed lands. The thermal regime was also improved, since the soil was cooled by water evaporation. Normally in spring, the river flooded the Lower Euphrates valley from time to time. When this happened, the water was diverted into special water-storage reservoirs, from whence it could be periodically fed to the fields during times of growth. Another method was used for taming the river in the Indus valley in the middle of the third millennium B.C.

At first, reclamation systems were adopted not in the whole river basin, but in individual fields. Later, the irrigated areas expanded as neigh boring communities began to cooperate, and great progress was made. This great achievement was due to the inhabitants' high degree of organization and cooperation. Agricultural reclamation over a wide area required a high level of organization to coordinate the work of many workers towards a single plan; this was one of the major achievements of early civilizations.

Use of river water for large-scale irrigation at that time in history (i.e. the Stone Age and Bronze Age) was possible only in places where the soil was soft enough, the river banks were not too steep and rocky, and the current was not too fast. Therefore, because of these physical conditions, even in the subtropical desert-steppe, steppe and forest-steppe zones, many rivers, including the Tigris (adjacent to the Euphrates), the Arax and Kura, Syr Darya and Amu Darya, etc., could not be the basis of irrigation civilizations until much later (Gumilev, 1989).

The efficacy of irrigation was highest in places where deep sediment from floodwaters formed the soil. Crops began to flourish when plough tillage was introduced (first by donkeys and later by oxen). This technology remained virtually unchanged for several millennia.

It was by the end of the fourth millennium BC in Egypt and Sumer (southern Mesopotamia) that crop yields multiplied greatly, by a factor of ten or even twenty. This meant that every farmer could produce much more than was required for his own needs. This led to favourable developments in cattle breeding, which in turn led to an even greater rise in people's living standards. Each community was able not only to support its workers but also the disabled and dependents, e.g. children and old men. They were able to create a reserve of foodstuff and to free a part of the workforce from agricultural labour.

1.5 Societies of the floodplains

At this time, specialized crafts began to appear: pottery, weaving, shipbuilding, stonecutting, tin forging, etc. Thus, the development of agricultural reclamation served as the beginning of commercial production development. In due course, reclamation systems were developed, and areas were expanded. In the fourth millennium B.C., several smaller canals were created to take water from each of main river watercourses, and by constructing a system of weirs and reservoirs it became possible to hold the water back for regular irrigation of the fields during the whole growth period.

It is necessary to note that not only irrigation, but also drainage was developed at this time, and there were separate irrigation and drainage floodplain systems.

By controlling the prolific silt precipitation, they also achieved a measure of regulation over nutrient supply. We can safely say, therefore, that at the earliest stages of its development, agricultural reclamation was complex, with systems to control water supply, nutrient supply and, to a certain extent, the thermal regime of agricultural lands. As a result of this progress, crops increased and it was possible to accumulate foodstuffs.

Qualified specialists were required for construction and maintenances of the reclamation systems, during their operation, and these functions (e.g. canal construction and clearing, and construction of other earthworks) were generally accomplished (according to Gumilev) not by slaves, but by community members.

Each free adult was obliged to spend, on average, one to two months each year on these works, throughout the history of ancient Mesopotamia. Free community members also carried out the basic agricultural operations, e.g. tillage and sowing. Archaeological examination of traces of the most ancient settlements in Lower Mesopotamia has revealed that the process of improving the local reclamation systems was accompanied by removal of small settlements of family farms.

These people moved into city centres, where the main temples, with their rich barns and workshops, were situated. The temples served as centres for inventories and management; from here, on behalf of the leading officials, traders travelled to other countries to exchange the food and textiles of Lower Mesopotamia for timber, metals, and slaves.

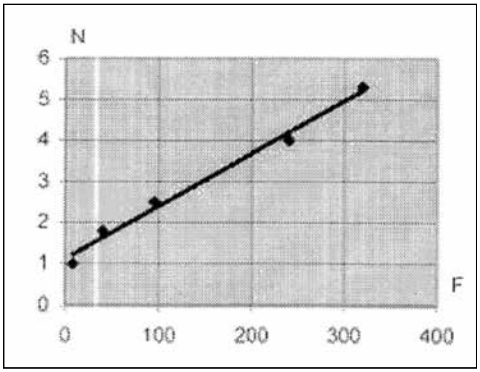

Figure 1.1. Dependence between the irrigated area in the World (F) and the population on the Earth (N).

At the beginning of the second quarter of the third millennium B.C., the densely populated areas around the main temples were enclosed within town walls. By about 3,000 to 2,900 B.C., temple facilities had become so complex and extensive, that records of their economic activities became necessary, and as a result, written language was generated. Over about 500 years, a written system of characters resembling subjects was transformed into an ordered system of information transmission. This was achieved by about 2400 B.C. Thus, it is possible to state that agricultural reclamation also provided the stimulus for development of human culture.

Although the ancient world had irrigated areas comprising hundreds of thousands of hectares, widespread development of reclamation was not achieved until much later. Over the last hundred years there has been a straight line relationship between irrigated area and world population, i.e. irrigated area per capita remains constant, approximating to 0.07 ha per inhabitant of the globe (see Figure 1.1). In other words, about 14 people rely on the production from every irrigated hectare.

1.6 Development of agricultural tools

The evolution of digging tools has played an important role in the development of irrigation practices. The first tool utilized by farmers for irrigation was a stick. Early on there was no tillage, and sowing was directly into wet soil.

However, even in this case, the stick was often used for seed incorporation, as was testified by ethnographical observations. In 1968, Axel Steensberg, a great connoisseur of the history of agricultural tools, discovered a number of wooden agricultural tools in the mountain regions of New Guinea, including a small stick with a sharp edge and a short paddle-like spade for ditch digging.

In China, flood control came into practice about 200 BC. At that time, treatises were published on the management of river water, flood control, and canal construction. The famous dam on the Tu-Klang River with a water reserve sufficient to irrigate more than 2,000 km^2 of paddy fields was constructed during the Chin dynasty in the third century BC. The equipment for lifting water from a river for irrigation was under development. The 1,125 km long Grand Canal was constructed during the Sui dynasty, in the late sixth and early seventh centuries of our era. Irrigation, drainage, and flood control in China have a history dating back more than 5,000 years. The history of irrigation in southern India and the island that is known now as Sri Lanka covers more than 3,000 years. Sri Lanka was totally covered with an irrigation network as early as 3,000 BC, and irrigation ensured two yields per year. Protective dams and distribution canals have been in use for 6,000 years. In Latin America, the remains of irrigation canals, dams, and drainage have been found from the ancient Maya culture.

1.7 Agricultural reclamation in recent times

Figure 1.2 shows the curve of increase in the area of irrigated land in the nineteenth and twentieth centuries. As seen in Figure 2, the irrigated area increase can be approximated to an exponential dependence. In the 1960s, the rate was slightly higher, and in the 1980s it slowed. It is visible if we create a logarithmic graph (Figure 1.3).

In the future, the rate of increase of irrigated land must slow down, as the total irrigated area will be limited by water resources and suitability of the land.

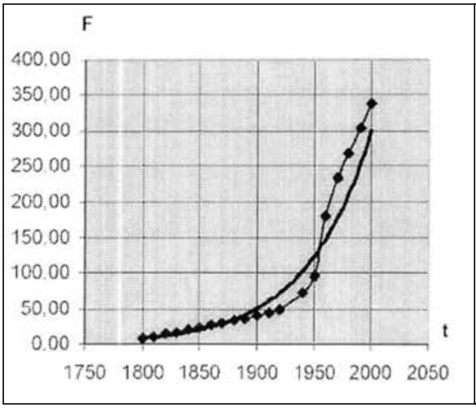

Figure 1.2. Increase in the global area of irrigated land

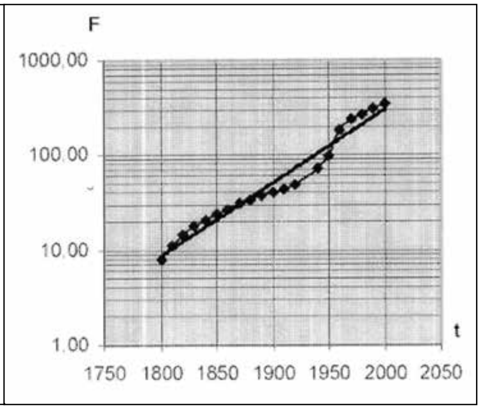

Figure 1.3. Increase in the global area of irrigated land, on a logarithmic scale.

The global area of drained land is smaller than the irrigated area, and, as at 1995, totaled about 200 mln ha (last data by ICID 2014 - 197.6 mln). The Greek historian Herodotus first described the drainage of agricultural lands more than 2,000 years ago. According to his description this system was created for collecting water after high river floods. In the Middle Ages, in northern Europe, drainage systems became widespread, along with the extensive development of new agricultural land and drainage of urban land, particularly during the tenth century in the Netherlands and Great Novgorod of Russia. Thus, it is possible to say that agricultural reclamation is one of the most ancient spheres of human activity, and one which enabled humankind to prosper. Construction of large reclamation systems was always evidence of a powerful state, and destruction of reclamation systems, during wars or due to inappropriate operation, contributed to the failure of states.

Reclaimed land areas, in particular irrigated land, comprises about 10-15% of the ploughed areas of the Earth, but they are responsible for about 30% of the production (in money terms). Hence, in order to supply the growing population with food, a constant input of new reclaimed land is required, in addition to intensification of agriculture on existing reclaimed land. According to UN experts, to resolve the global food problem, the irrigated area should be increased by 0.5% annually.

At the same time, to ensure stable agriculture, the distribution of irrigated lands, in terms of natural-climatic zones should be in excess of 20 to 25% in the arid zone, 10 to 20% in dry steppe; 5 to 10% in steppe, and 1 to 5% in forest-steppe (Maslov 1999).

Nowadays, vast irrigated areas are located in India, China, Pakistan, Egypt, Iran, USA, and Russia. Apparently, lack of available water resources will remain the principle limiting factor in the expansion of irrigated land. This applies to all the relevant countries, except for Brazil and Russia. Undoubtedly, the scale of new reclamation development will depend on population increase and global climate change, but the quantitative increase of irrigated and drained land will become less important than the quality of agricultural reclamation. As described above, in ancient times reclamation systems were complex, i.e. they were constructed in such a way that they were able to control not only water, but also nutritional, thermal and other environmental factors. Modern reclamation systems do not always possess such properties, because basically only the regulation of water flow is controlled. Using ecological principles, it is possible to believe that creating more sophisticated reclamation systems will permit significant increases in crop production (not less than 30-50%) on existing reclaimed lands, and this can reduce the gap between population growth and creation of new areas of reclaimed land. Today, the concept of complex reclamation regulation is sufficiently developed. The systems have been proved, and in future, their area and importance can only increase.

We will now consider in more detail the different kinds and methods of agricultural reclamation. Table 1.1 sets out the methods and objectives of regulation, including hydraulic engineering, climatic, technical crops, edaphic, chemical, agricultural and forest reclamation, phyto-reclamation, reclamation of water used for irrigation.

1.8 The reasons for land reclamation

It is well-known, that the ancestors of modern agricultural crops were formed in such a way that conditions in the sites of their origin became ecologically optimum for given species. Farmers cultivating wild plants by artificial selection, has raised their efficiency, but at the same time an external conditions changing stability which was peculiar to given species has been partly lost.

Using selection, agronomist and farmers have selected and have reproduced an extremely productive plants which 50-100 times exceeded productivity of their far ancestors. But under a high productivity a self-regulation (adaptation) opportunity of plant are essentially (3-5 times) reduced. A size of crop begin to depend essentially upon factors, which are small on their absolute magnitude (microcells, micro dozes of toxic gases etc.) but which become limiting under an optimum level of the other factors.

Besides, during its migration from one area in another the mankind transferred plants to areas with very different environment which were not optimum for the given species any of influences, contradictions have arisen between natural biological systems (soil biota and water objects) and conditions of environment changed by a man. The result is that since the certain level, an essential increase of crops may be received only if all factors influencing growth and development of plants are regulated. Thus, the contradiction between desire of man to receive a high productivity of plants and impossibility to do it without exact regulation of set of factors of an environment has resulted in melioration appearance. Necessity of radical improvement of properties of land and conditions of an environment arises not only at agricultural activity, and for other lands.

According to it there are various kinds of melioration:

- Land reclamation of agricultural purpose;
- Land reclamation of settlements;
- Melioration of grounds, occupied with the industry, transport, communications, defense;

Table 1.1. Kinds and methods of reclamation (according Maslov and Shabanov)

Reclamation type	Reclamation kind	Reclamation methods
I. Hydraulic engineering reclamation	1. Drainage	Water removal, drainage
	2. Irrigation	Sprinkling, surface watering
	3. Humidifying	Water retention
	4. Watering	Water supply to the territory
	5. Flood-control (flood protection)	Water-storage reservoirs, dams construction
	6. Hydraulic forest reclamation	Forest irrigation
	7. Water reservoirs reclamation	Water reservoirs clearing
	8. Soil-saving	Ravine reinforcement
	9. Mudflow protection	Mudflow protection structures
	10. Landslide protection.	Decrease of watering, ground
	11.Agro-reclamation.	Narrow-cut plowing, roll contouring.
II. Climatic	12. Snow	Snow retention on the fields, snow blackening to accelerate melting, snow clearing.
	13. Thermal	Soil surface mulching
	14. Frost protection	Anti-frost sprinkling, fuming
	15. Artificial precipitates inducing	Cloud seeding with water-drop forming reagents
	16. Hot wind protection	Agro-forest reclamation, aerosol moistening.
	17. Land surveying	Fields agglomeration, creation of fields with a uniform water regime and fertility.
	18. Soil surface reclamation	Stones, brush and low-forest removal from the arable lands, mossy tow removal, hummock finishing, grading
	19. Plowed soil layer reclamation	Buried stones and wood removal
III. Technical crops		
IV. Edaphic	20. Structural	Addition of sand, clay and peat, soil structure-forming with chemical reclaiming reagent application, deep tallage
	21. Reclaiming	Quarry land, lake and sea bay bed development
	22. Sands reclamation	Water-holding capacity of soil increase, feeding organics (e.g. peat)
	23. Sedimentation	Creation of soil with the help of silt precipitation
V. Chemical	24. Soil acidity control	Liming, gypsuming
	25. Salt protection	Chemical reagents application, soil flushing, drainage
	26. Solonetz reclamation	Gypsuming, deep tallage, phyto-reclamation
	27. Oxidant	Oxygen-containing fertilizers application
	28. Fertilizing	Mineral and organic fertilizers application
VI. Agro-forest, reclamation, phytoreclamation	29. Erosion preventive	Forest shelter belts

Table 1. Kinds and methods of reclamation (according Maslov and Shabanov)

	30. Anti-deflation (soil protective)	Biologic drainage, harrowing, planting beds and gaps control
VII. Reclamation of water used for irrigation	31. Irrigation water acidification	
	32. Sprinkling water chemical composition optimization	
	33. Warming cold sprinkling water	
	34. Sewage water treatment	

- Land reclamation of wood fund (but not wood melioration);
- Land reclamation of water fund (for example, preparation of reservoir floor);
- Land reclamation of historical-cultural, sanitary and recreational purposes.

A necessity of radical improvement of environment conditions arises in cases:
- If the highly productive agricultural crop is cultivated which was obtained by selection from a plant originated in given native-climatic conditions.
- If the plants are cultivated under conditions, which are not really optimum for them, for example, on soils which properties are far from those in an area of the origin of these plants.

Thus, the contradiction between requirements of plants and conditions of an environment has served as driving force of development of land reclamation. Further at the big scales of influences, contradictions have arisen between natural biological systems (soil biota and water objects) and conditions of environment changed by a man. The result is that since the certain level, an essential increase of crops may be received only if all factors influencing growth and development of plants are regulated. Thus, the contradiction between desire of man to receive a high productivity of plants and impossibility to do it without exact regulation of set of factors of an environment has resulted in melioration appearance

1.9 Kinds of land reclamation

Land reclamation of the agricultural lands is subdivided into kinds according to the adjustable factor:
- *Water melioration of soils* (hydro melioration) regulating amount of moisture in soil by an irrigation or drainage, agro-forest melioration (creation of forest

World Irrigated Area

(Arranged in descending order of the irrigated area)

Sl. No.	Country	Irrigated Area Million ha	Reference Year
	DEVELOPED COUNTRIES		
1	**USA**	**24.74**	2009[2]
2	**Spain**	**3.605**	2014[1]
3	**Japan**	**2.920**	2013[1]
4	**France**	**2.900**	2011[1]
5	**Australia**	**2.550**	2011[2]
6	**Italy**	**2.420**	2010[1]
7	*Greece*	*1.555*	2011[2]
8	**Romania**	**1.500**	2008[1]
9	**Canada**	**1.053**	2004[1]
10	New Zealand	0.619	2011[2]
11	**Portugal**	**0.540**	2011[2]
12	*Germany*	*0.516*	2011[2]
13	**Netherlands**	**0.486**	2011[2]
14	Denmark	0.435	2011[2]
15	**Hungary**	**0.208**	2004[1]
16	Sweden	0.164	2011[2]
17	**Czech Rep.**	**0.153**	2011[1]
18	*Slovak Republic*	*0.135*	2011[2]
19	*Austria*	*0.117*	2011[2]
20	*Poland*	*0.116*	2011[2]
21	*Bulgaria*	*0.102*	2011[2]
22	**Ireland**	**0.100**	2010[1]
23	Norway	0.090	2011[2]
24	**UK**	**0.084**	2010[1]
25	**Finland**	**0.080**	2009[1]
26	Cyprus	0.046	2011[2]
27	**Switzerland**	**0.040**	2007[1]
28	Belgium	0.023	2011[2]
29	**Slovenia**	**0.007**	2011[1]
30	*Lithuania*	*0.004*	2011[1]
31	Malta	0.003	2011[2]
32	Latvia	0.001	2011[2]
	Sub-Total	**47.312**	

Sl. No.	Country	Irrigated Area Million ha	Reference Year
	EMERGING/DEVELOPING COUNTRIES		
1	**India**	**62.000**	2010[1]
2	**China**	**60.004**	2010[1]
3	**Pakistan**	**19.080**	2013[1]
4	**Iran**	**8.570**	2015[1]
5	**Indonesia**	**6.722**	2011[2]
6	**Mexico**	**6.500**	2011[2]
7	**Turkey**	**5.730**	2012[1]
8	**Thailand**	**4.736**	2011[1]
9	Vietnam	4.600	2011[2]
10	**Russia**	**4.500**	2007[1]
11	**Brazil**	**4.453**	2006[1]
12	**Uzbekistan**	**4.260**	2014[1]
13	**Egypt**	**3.670**	2011[2]
14	**Iraq**	**3.525**	2011[2]
15	*Ukraine*	*2.180*	2009[1]
16	**Kazakhstan**	**2.122**	2007[1]
17	Turkmenistan	1.869	2013[1]
18	**Saudi Arabia**	**1.731**	2011[2]
19	Argentina	1.650	2011[2]
20	**South Africa**	**1.600**	2007[1]
21	**Phillipines**	**1.520**	2008[1]
22	Korea, DP Rep	1.460	2011[2]
23	**Morocco**	**1.458**	2011[2]
24	Azerbaijan	1.430	2013[1]
25	*Syria*	*1.399*	2011[2]
26	Peru	1.196	2011[2]
27	Chile	1.090	2007[1]
28	Colombia	1.087	2011[2]
29	Venezuela	1.055	2011[2]
30	*Kyrgyz Rep.*	*1.020*	2011[2]
31	**Korea Rep.**	**1.010**	2009[1]
32	Ecuador	1.000	2011[2]
33	Cuba	0.870	2011[2]
34	**Tajikistan**	**0.804**	2013[1]
35	Algeria	0.570	2011[2]
36	**Sri Lanka**	**0.570**	2011[2]
37	Libya	0.470	2011[2]
38	Tunisia	0.459	2011[2]
38	Georgia	0.433	2011[2]
40	**Malaysia**	**0.385**	2009[1]
41	**Chinese Taipei**	**0.380**	2009[1]
42	Albania	0.331	2011[2]
43	Guatemala	0.315	2011[2]
44	Dominican Rep.	0.307	2011[2]
45	**Nigeria**	**0.293**	2011[2]
46	Moldova Rep.	0.228	2011[2]
47	*Israel*	*0.225*	2011[2]
48	*Uruguay*	*0.218*	2011[2]
49	Bolivia	0.175	2011[2]
50	**Zimbabwe**	**0.174**	2011[2]
51	*Guyana*	*0.150*	2011[2]
52	Belarus	0.131	2011[2]
53	*Macedonia*	*0.128*	2011[2]
54	Costa Rica	0.108	2011[2]
55	Kenya	0.103	2011[2]
56	Jordan	0.096	2011[2]
57	*Serbia, Republic of*	*0.092*	2011[2]
58	United Arab Emirates	0.092	2011[2]
59	Lebanon	0.090	2011[2]
60	Honduras	0.088	2011[2]
61	Mongolia	0.084	2011[2]
62	Ivory Coast	0.073	2011[2]
63	Paraguay	0.067	2011[2]
64	Nicaragua	0.061	2011[2]

World Drained Area

Sl. No.	Country	Arable land and permanent crops (Mha)	Total drained area (Mha)	% drained area	Reference year
	DEVELOPED COUNTRIES				
1	Australia	44.37	2.17	4.89	2002[2]
2	Austria	1.44	0.2	13.89	1997[2]
3	Belgium	0.87	0.07	8.05	1996[2]
4	Bulgaria	3.25	0.08	2.46	2000[2]
5	Canada	67.5	9.46	14.01	2002[2]
6	Cyprus	0.11	0.02	18.18	2000[2]
7	Czech Rep.	3.26	1.07	32.82	2011[1]
8	Denmark	2.35	1.77	50.00	2012[1]
9	Estonia	1.33	0.64	48.00	2013[1]
10	Finland	2.26	2.5	110.62	2008[1]
11	France	19.33	3.00	15.52	2011[1]
12	Germany	12.13	4.9	40.40	1993[2]
13	Greece	3.23	0.52	16.10	2002[2]
14	Hungary	4.8	2.3	47.92	2003[1]
15	Ireland[4]	1.06	0.254	23.96	2010[1]
16	Italy	13.2	5.3	40.15	2005[1]
17	Japan	4.55	3.52	77.36	2012[1]
18	Latvia	1.18	1.58	133.90	1995[2]
19	Lithuania[5]	2.68	2.58	96.27	2011[1]
20	Netherlands[6]	1.09	3.0	275.23	2010[1]
21	Norwegian	1.02	0.61	60	2012[1]
22	Poland	12.97	4.21	32.46	1999[2]
23	Portugal	1.64	0.04	2.44	2002[2]
24	Romania	9.85	1.83	18.58	2008[1]
25	Slovak Republic	1.41	0.6	42.55	1997[2]
26	Slovenia	0.2	0.08	40.00	2007[1]
27	Spain	24.90	0.3	1.205	2014[2]
28	Sweden	2.64	1.1	41.67	1996[2]
29	Switzerland	0.43	0.16	37.21	2002[2]
30	UK	6.05	4.65	76.86	1996[2]
31	USA	173.2	47.5	27.42	1987[3]
	Sub-Total	**424.3**	**106.014**	**24.98**	
	EMERGING/DEVELOPING COUNTRIES				
32	Albania	0.7	0.28	40.00	1999[2]
33	Algeria	8.42	0.06	0.71	1999[2]
34	Argentina	33.0	0.13	0.40	2002[2]
35	Azerbaijan	2.09	0.61	0.29	2013[1]
36	Belarus	5.64	3.0	53.19	1993[2]
37	Bolivia	3.82	0.02	0.52	2000[2]
38	Brazil	66.9	1.08	1.61	2013[1]
39	Chile	0.78	0.035	4.49	2006[1]
40	China	130.03	21.14	16.26	2008[1]
41	Chinese Taipei	0.80	0.13	16.25	2012[1]
42	Colombia	3.46	0.23	6.65	1989[2]
43	Costa Rica	0.5	0.04	8.00	1999[2]
44	Croatia	0.95	0.76	80.00	1990[2]
45	Cuba	3.97	0.33	8.31	1997[2]
46	Dominican Rep.	1.30	0.03	2.31	2000[2]
47	Ecuador	2.50	0.05	2.0	1998[2]
48	Egypt*	3.54	3.36	85.31	2011[1]
49	El Salvador	0.92	0.01	1.09	1997[2]
50	Fiji	0.25	0.01	4.00	2000[2]
51	Georgia	0.58	0.16	27.59	1996[2]
52	Guyana	0.45	0.15	33.33	1991[2]
53	Honduras	1.43	0.06	4.20	1991[2]
54	India	169.32	5.8	3.43	1991[2]
55	Indonesia	37.10	3.35	9.03	1990[2]
56	Iran	14.8	0.28	1.89	2015[1]
57	Iraq	5.45	1.54	28.26	2002[2]
58	Israel	0.38	0.1	26.32	1987[3]
59	Jordan	0.15	0.01	6.67	2008[3]
60	Kazakhstan	22.8	0.45	1.97	2013[1]
61	Kenya	5.8	0.03	0.52	2003[2]
62	Korea Rep.	1.82	1.15	63.19	2007[1]
63	Kyrgyz Rep.	1.35	0.20	14.81	2013[1]
64	Lebanon	0.29	0.01	3.45	2001[2]
65	Libya	2.05	0.01	0.49	2000[2]
66	Malaysia	9.5	6.0	63.16	2009[1]
67	Mexico	27.50	5.2	18.91	1997[3]
68	Mongolia	0.85	1.5	176.47	2000[2]
69	Morocco	8.98	0.65	7.24	2004[2]
70	Pakistan	30.40	7.86	25.85	2013[1]
71	Paraguay	4.3	0.01	0.23	2000[2]
72	Peru	4.44	0.08	1.80	2000[2]
73	Philippines	9.16	2.72	29.69	2008[1]
74	Puerto Rico	0.1	0.02	20.00	2000[2]
75	Russia	192.6	4.78	2.48	2007[1]
76	Saudi Arabia	3.68	0.04	1.09	1992[2]
77	Serbia & Montenegro	3.72	0.4	10.75	2000[2]
78	South Africa	18.00	0.06	0.41	2011[1]
79	Sri Lanka	2.20	0.03	1.36	1967[4]
80	Surinam	0.06	0.05	83.33	1998[2]
81	Syria	5.68	0.27	4.75	1993[2]
82	Tajikistan	0.87	0.33	37.93	2013[1]
83	Thailand	18.85	0.16	0.85	1997[2]
84	Tunisia	5.04	0.2	3.97	2000[2]
85	Turkey	26.01	3.43	13.19	2012[1]
86	Turkmeni-stan	1.92	1.1	57.29	2013[1]
87	Ukraine	33.5	3.3	9.85	2013[1]
88	Uzbekistan	4.7	3.3	70.21	2014[1]
89	Venezuela	3.35	0.31	9.25	2002[2]
90	Vietnam	9.42	1.0	10.62	1994[2]
91	Zimbabwe	11.00	0.1	0.90	2011[1]
	Sub-Total	**969.17**	**87.505**	**9.03**	
	LEAST DEVELOPED COUNTRIES				
92	Afghanistan	7.91	0.01	0.13	2000[2]
93	Bangladesh	8.70	1.5	17.24	1993[2]
94	Ethiopia	14.51	0.03	0.21	1987[3]
95	Madagascar	3.55	0.11	3.10	2000[2]
96	Malawi	7.7	NA	-	2002[1]
97	Myanmar	11.70	0.19	1.62	1994[2]
98	Nepal	2.47	0.09	3.64	2000[2]
99	Rwanda	1.57	0.09	5.73	2000[2]
100	Sudan	20.91	0.56	2.68	2000[2]
101	Yemen	1.61	1.5	93.17	2000[2]
	Sub-Total	**80.63**	**4.08**	**5.06**	

Sprinkler and Micro Irrigated Area

(Arranged in descending order of the total sprinkler and micro irrigated area)

S. No.	Country	Total irrigated area (Mha)	Sprinkler irrigation	Micro Irrigation	Total sprinkler and micro irrigation	Percentage of total irrigated area	Year of reporting
			Hectares				
1	USA	24.7	123,48,178	16,39,676	139,87,854	56.5	2009
2	India	60.9	30,44,940	18,97,280	49,42,220	8.1	2010
3	China	59.3	29,26,710	16,69,270	45,95,980	7.8	2009
4	Brazil	5.80	38,57,104	6,21,346	44,78,450	77.3	2013
5	Spain	3.61	8,52,189	17,56,138	26,08,327	72.4	2014
6	Russia	4.5	25,00,000	47,000	25,47,000	56.6	2012
7	Ukraine	2.2	24,50,000	52,000	25,02,000	100.0	2013
8	France	2.9	13,79,800	1,03,300	14,83,100	51.1	2011
9	Kazakhstan, Rep. of	1.2	14,00,000	17,000	14,17,000	100.0	2013
10	Iran	8.57	8,02,000	5,94,000	13,96,000	16.3	2015
11	Italy	2.42	9,58,535	4,22,534	13,81,069	57.1	2013
12	South Africa	1.67	9,20,059	3,65,342	12,85,401	77.0	2007
13	Turkey	5.73	6,80,000	3,40,000	10,20,000	17.8	2012
14	Saudi Arabia	1.62	7,16,000	1,98,000	9,14,000	56.4	2004
15	Australia	2.38	6,90,200	2,14,200	9,04,400	38.0	2005
16	Canada	1.053	6,83,029	6,034	6,89,063	65.4	2004
17	Azerbaijan	1.433	6,10,000	100	6,10,100	42.6	2013
18	Korea, Rep. of	1.010	2,00,000	4,00,000	6,00,000	59.4	2009
19	Mexico	6.2	4,00,000	2,00,000	6,00,000	9.7	1999
20	Egypt	3.42	4,50,000	1,04,000	5,54,000	16.2	2000
21	Germany	0.54	5,25,000	5,000	5,30,000	98.1	2005
22	Japan	2.92	4,30,000	60,000	4,90,000	16.8	2013
23	Romania	1.5	4,48,000	4,000	4,52,000	30.1	2008
24	Slovak Rep.	0.313	3,10,000	2,650	3,12,650	99.9	2000
25	Israel	0.231	60,000	1,70,000	2,30,000	99.6	2000
26	Morocco	1.65	1,89,750	8,250	1,98,000	12.0	2003
27	Hungary	0.22	1,85,000	7,000	1,92,000	87.3	2008
28	Moldova	0.228	1,45,000	15,000	1,60,000	70.2	2012
29	Syria	1.28	93,000	62,000	1,55,000	12.1	2000
30	Austria	0.117	1,17,000	20,000	1,37,000	100.0	2011
31	UK	0.11	1,05,000	6,000	1,11,000	100.0	2005
32	Finland	0.07	60,000	10,000	70,000	100.0	2010
33	Portugal	0.63	40,000	25,000	65,000	10.3	1999
34	Malawi	0.055	43,193	5,450	48,643	88.4	2000
35	Sudan	1.89	42,000	-	42,000	2.2	2012
36	Chile	1.09	16,000	23,000	39,000	3.6	2006
37	Chinese Taipei	0.38	18,850	8,750	27,600	7.3	2009
38	Bulgaria	0.588	21,000	3,000	24,000	4.1	2008
39	Czech Rep.	0.153	11,000	5,000	16,000	10.5	2007
40	Philippines	1.52	7,175	6,635	13,810	0.9	2004
41	Poland	0.1	5,000	8,000	13,000	13.0	2008
42	Slovenia	0.0073	8,072	733	8,805	100.0	2009
43	Uzbekistan	4.26	5,000	2,000	7,000	0.2	2014
44	Malaysia	0.38	2,000	5,000	7,000	1.8	2009
45	Macedonia	0.055	5,000	1,000	6,000	10.9	2008
46	Nepal	1.18	-	-	5,000	0.4	2012
47	Burkina Faso	0.04	4,500	280	4,780	12.0	2015
48	Lithuania	0.0044	4,463	-	4,463	100.0	2010
49	Estonia	0.002	100	500	600	30.0	2013
50	Iraq	3.52	-	-	159	0.0	2012
	Total	**225.63**	**407,69,847**	**111,11,468**	**518,86,474**	**23.0**	

belts for detention of moisture and reduction of evaporation), agro melioration actions (ploughing, harrowing, mulching etc.).

- *Chemical land reclamations* – i.e. a regulation of amount of chemical substances: application of fertilizers, desalination of soils, change of reaction of soil solutions (for sour soils - liming, for solonetzes - plastering).
- *Thermal land reclamations* - i.e. a regulation of amount of heat in soil: cooling humidifying, frost control, direct heating (for example, using a heat from thermal power stations), changing of thermos physical properties of soil: change of reflecting ability of soil (albedo) by means of mulching; changing of thermal capacity and heat conductivity of soils (changing of structure of a firm phase - density, friability), addition of sand, for example, (the ground becomes more friable in this case and faster dries up), addition of organic substance in order to increase a moisture capacity; deep loosening. Creation of an artificial relief results in changing of physical properties: porosity, density, water and air permeability.

The best effect is achieved by using a complex land reclamations, i.e. a joint application of several kinds of land reclamation on the same site of the grounds. In connection varying of plant requirements in the various periods of their development, a necessity of providing in each territory a required meliorative mode (i.e. change of the basic conditions of an environment depending on time) arises.

According to definition a meliorative mode (i.e. a set of requirements applying to the controlled factors of soil formation and development of plants) provides an overall objective of land reclamation of the agricultural grounds. The basic parameters of a meliorative mode:

- Permissible limits of soil humidity in a root-inhabited layer;
- Permissible limits of depths of subsoil waters;
- A permissible direction and size of water exchange between the soil layer, spreading ground and subsoil waters;
- Permissible limits of contents of toxic salts, pH,
- Permissible balance of humus and nutrients;
- A permissible mineralization of irrigation waters;
- Permissible limits of amount and quality of outflow from drainage and irrigation systems.

It follows from the definition of land reclamation which has been given by Kostiakov, that primary goal of agriculture and land reclamation is management of a water cycle and cindery nutritious elements with a view of progressive increase of soil fertility. Management of these processes is carried out by shifting water and cindery elements from geological circulation into a biological one. It allows to prove their connection with circulation of energy because a transference of the cindery elements into biological circulation becomes possible after having accumulated them in a biomass, and it, in turn, can be made only under an influence of a solar energy. Kostiakov considered it possible to carry out such a management by complex melioration, i.e. the hydraulic engineering and agro technical influences regulating water, air, thermal, food and consequently a biological mode of soil.

Shabanov proposed to consider a complex land reclamations as a science about radical improvement (optimization) of all vital for plant factors of an environment. Technically complex land reclamation is a system of the procedures allowing essentially to increase a productivity of plants by means of influence on the factors of an environment which are basic for its growth and development.

1.10 Consequences of land reclamation

An obligatory condition of a consequence complex land reclamations should be a progressing increase of fertility of soils and prevention of negative influence on all components biogeocenoses. Thus, the systems of complex meliorative regulation are a dialectically caused product of interaction of man and environment, produced during the long attempts of man to increase the productivity of natural biogeocenoses. Last time, land reclamation becomes necessary for the grounds which are liable to ecological accidents and disasters, where the steady natural landscapes are destroyed.

In this case there is a progressing loss of fertility of grounds, which is fraught with serious social – ecological consequences for life of many countries. Besides each country is liable to periodic changes of climate which may last for some years. It may result in essential changes of structure of natural biogeocenoses, changes of landscape and social instability. Methods of complex meliorative regulation may be also used for stabilization of natural ecosystems.

Having considered the positive features of land reclamation, it is necessary to note also its negative features. Only a few systems "are authorized" to make the basic changes of an environment. The necessity of procedures which change the nature, especially in the sphere of production of agricultural products, is fixed in our mind for a long time and it is promoted the formation of positive public opinion. There is no need to explain people that lives in deserts or in areas which are liable to recurrent droughts. Then irrigation is a good thing, and it is not necessary to explain the benefits of the drainage to the people that lives in marshlands.

On the one hand there are growing requirements of preservation and non-interference into nature, on the other hand – there are resolute requirements to provide an acceptable quality of life in a society, and this will inevitably result in the further intensification of all spheres of production including agricultural melioration.

Now there is no alternative for the land reclamation of agricultural grounds (in the broad sense of melioration). The quality of an environment at all stages of man development occupied a special position. In the majority of areas an environment does not correspond to human biological features and historical generated requirements for conditions, comfort and convenience of life and labour. Transformation of a nature, an aspiration to arrange a nature, to bring it into accordance with the usual centuries representations concerning a quality of life and requirements to the vital space, unlimited use of natural resources were and unfortunately remain a dominant direction of activity of the person who have developed the appropriate systems of activity and have created a necessary sections of fundamental and applied knowledge.

Since agriculture became cultural, it is necessary to remember constantly that agricultural crops may not live in any given conditions. In that case they either do not grow absolutely, or are unproductive. Precisely it is required to fix that fact that soil of an arable land and other agricultural grounds are not those soils which were formed evolutionally. There is no matter that many soils are already degraded or may degrade. The matter is that without cultivation the grounds could not have a necessary level of fertility at all. They should be constantly improved, meliorated, and thus there are no basic differences between agro procedures and engineering meliorations. If we want to receive an acceptable level of a crop then in any case it is achieved through technologies. The greater crop is required, the more intensive technology should be used and more precise an accuracy of necessary batching of providing of anthropogenous resources mast be. It is also actual from the other points of view: in practice anthropogenous substances (fertilizers, chemical weed-killer and returnable water) frequently pollute the rivers, reservoirs, subsoil waters, and natural fertility of soils is spent irrevocable.

With engineering melioration or without them – an agriculture carries out the largest of all kinds of activity intrusion in to biosphere, but there is no any alternative to agriculture. Therefore its rationality is also the basic ecological requirement.

The agricultural activity and also the meliorative one, which is closely connected to it should be carried out in conditions of the constant control and the responsibility. It is impossible to plan a development of an agricultural production in such conditions without an estimation of possible ecological consequences of all technological actions and receptions.

Undoubtedly, that now it is necessary to introduce widely the methods of complex melioration, which allow to raise crops essentially, to optimize an irrigation modes with a view of economy of water resources, to take into account cost of water and to make a choice of the best variant on this basis. In each project a natural necessity of land reclamation and its economic and social efficiency should be proved, and the ecological admissibility of realization of one or another kind of meliorative works should be estimated. Technically a complex land reclamation is a combination of "dry" (agro-phytomelioration) and "water" (hydraulic engineering) land reclamation. Such combination should be especially varied for each region, area or field.

It allows satisfy not only the requirements of plants, but also the requirements of soil biota i.e. to realize the certain meliorative mode which is a set of requirements to adjustable factors of soil formation provided a radical improvement and the further increasing of soil fertility, and getting the given crop of agricultural crops under the certain economic restrictions. Thus, land reclamations is carried out for the various purposes and the set of meliorative regulation types is various in every natural-climatic area.

Sources for chapter 1

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quantitative indices of discrepancy of crop demands to environment conditions. The developed method of calculation may be used for the purposes of planning and basing land reclamation on the vast territories.]
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Chapter 2
Soils

2.1 Soil as a life support system

Soil is the most basic of all natural resources. It is the three-dimensional layer of earth's crust, which, through numerous biophysical/chemical interactive processes, is capable of supporting plant and animal life and moderating air and water (environment) quality. Soil is a living entity, it is teeming with life, it is a substrate for plant growth, and ceases to support plant growth and purify water and air when life in it ceases to exist. Soil and life have evolved together and will continue to develop together. Because of its strong co-dependence on life, soils may be defined as "dynamic natural bodies comprising the uppermost layer of the earth, exhibiting distinct organization of their mineral and organic components, including water and air, which formed in response to atmospheric and biospheric forces acting on various parent materials under diverse topographic conditions over a period of time" (Yaalon, D.H. and R.W. Arnold. 2000). Soil, or the pedosphere, lies at the interface of the atmosphere and the lithosphere and interacts with all facets of the environment (Figure 2.1). Indeed, soil is in dynamic equi-

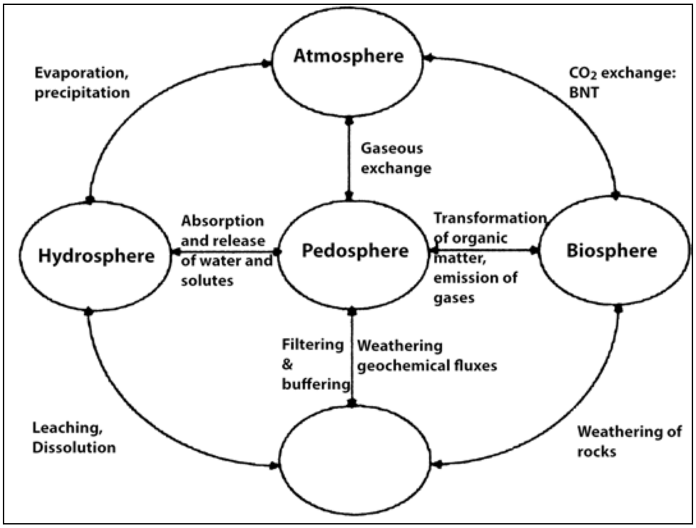

Figure 2.1. Interactions between Soil and the Environment

librium with its environment, it influences and is influenced by the environment. Soil's interaction with the lithosphere leads to weathering of rocks and new soil formation through leaching of organic and inorganic chemicals into the rock, penetration of plant roots and encroachment of other organisms.

Soil's interaction with atmosphere involves exchange of gases, notably CO_2 and N_2, with a profound impact on global climate and plant growth. Soil's interaction with hydrosphere affects water quality because of its ability to filter, denature and buffer against natural and synthetic compounds. It is soil's interaction with the biosphere that has led to co-evolution of life and soil. Soil is the most basic of all natural resources to human survival on the earth. Soil governs all basic processes that regulate the existence of life on earth.
These processes are:

- plant growth and biomass productivity,
- purification of water,
- detoxification of pollutants,
- recycling of elements
- resilience and restoration of ecosystems.

This part deals with the basic processes governing interaction between pedosphere and the biosphere, and describes future challenges for soil science to meet the demand of the 21st century and aspirations of the growing population.

2.2 Soil attributes

Soils are characterized by physical, chemical and biological attributes collectively termed as soil quality (Figure 2.2). Soil quality refers to its ability to perform functions of value to humans (Lal, R. 1997), but specifically to its capacity to produce biomass and moderate the environment (Doran at all., 1994, 1996). These attributes differ among soils because of their development/formation from specific parent material, climate, predominant vegetation, soil moisture regime, drainage intensity and position on the landscape (Jenny, H. 1980). Soil physical properties include particle size distribution, especially the amount of clay content and nature of clay minerals, degree and stability of aggregates, and total porosity and pore size distribution. These properties determine the relative proportion of solid: liquid: gaseous phases, and water retention and transmission properties.

Important processes governed by soil properties are gaseous exchange between soil and the atmosphere, root growth and development, soil erosion among others. Strongly interacting with physical properties are soil chemical charac-

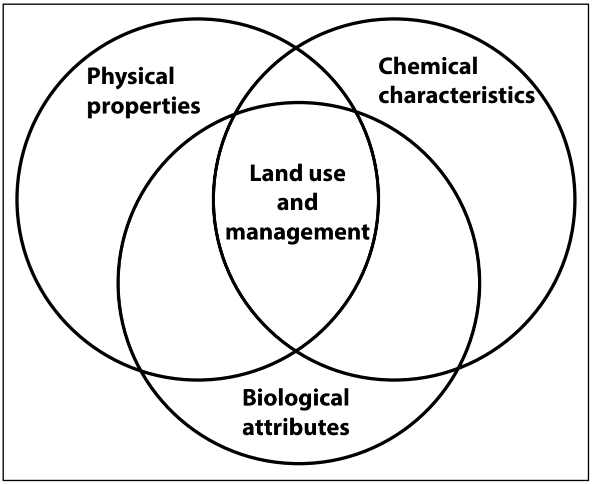

Figure 2.2. Soil quality depends on dynamic equilibrium between physical, chemical and biological properties and processes, and on land use and management.

teristics including pH, ion exchange capacity, elemental (N, P, S, K, Ca, Mg etc.) concentration and their solubility, and elemental balance as expressed by relative concentrations of predominant elements. Important processes relevant to soil chemical characteristics include leaching, acidification, ionic diffusion, chemical transformations and redox phenomena. Soil biological attributes, with strong impact on physical and chemical qualities, include quantity and quality of soil organic matter, total and microbial biomass carbon, and activity and species diversity of soil fauna. Soil processes associated with biological attributes are

- mineralization,
- fluxes of trace gases from soil to the atmosphere,
- purification of water and detoxification of chemicals and other pollutants.

Sustainable management of soil physical, chemical and biological qualities is the goal of adopting a judicious land use and appropriate management systems.

2.3 Soil exploitation and manipulation

Realizing that life depended on soil and its ability to support plant growth, ancient societies worshipped soil in one form or another (Hillel, D.J. 1991). Prior to the developments of modern science, inter-dependence of ancient human societies and soil occurred in three forms (Figure 2.3).

Soil exploitation. Humans have exploited soil resources for raising crops and animals, similar to a parasite's exploitation of its host organism, ever since the dawn of settled agriculture around 10-13 millennia ago (Hyams, E. 1952). Nat-

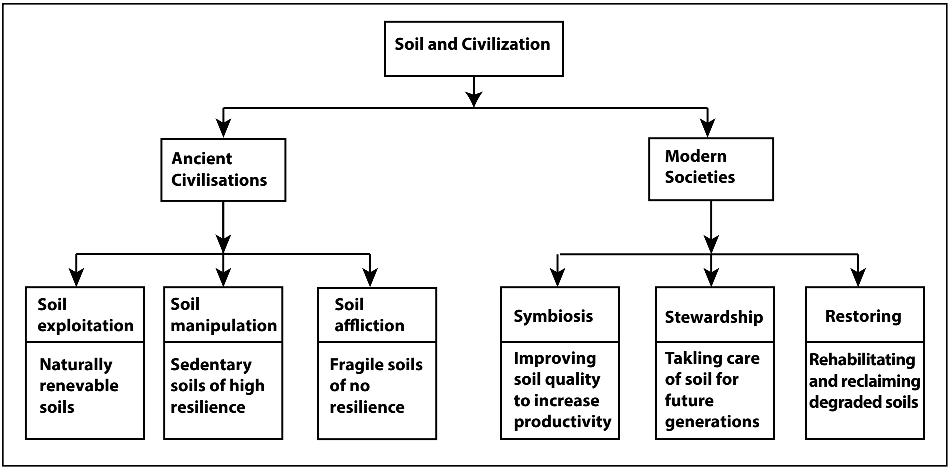

Figure 2.3. Soil-human interactions between ancient and modern civilizations

urally exploitable soils, supporting human settlement over a long period of time, comprised those that were frequently renewed by natural processes. A prime example is alluvial soils annually renewed by floods. The so called "hydric civilizations" (e.g., ancient cultures developed along the valleys of major river systems such as the Nile, Indus, Euphrates-Tigris, Yangtze etc.), exploited the natural renewability of alluvial soils (Hillel, D.J. 1991). With expansion of human settlement to other ecoregions, soil exploitation has been the basis of numerous traditional systems of farming such as shifting cultivation and bush fallow rotation (Greenland, D.J. 1974). Rather than annual floods, fertility of these upland soils was renewed by fallowing or abandoning the land for a long period of time.

Soil manipulation. Non-renewable soils cannot sustain plant/crop growth over a long period of time without alterations/manipulation of its life support processes. Principal systems of soil manipulation developed by ancient civilizations were ploughing, terracing, irrigation and manuring (fertilizing). Between 5000 and 4000 BC, Sumerian and other civilizations developed simple tools to place and cover seeds in the soil, which eventually evolved into a plough.

Cultivation of sloping lands, where accelerated soil erosion threatened sustainable use, led to evolution of the "terraced" system of farming. Terraced agriculture is a cultural tradition in many ancient civilizations in the Middle East (The Phoenicians), West Asia (Yemen), Central and South America (Incas) and South East Asia. Accelerated soil erosion has been a cause of the demise of many ancient cultures (Olson, G.W. 1981).

Crop production during dry season or in arid regions requires addition of water. Consequently irrigated agriculture evolved around 9500 to 8800 BC in the Middle East, and spread to other cultures (e.g., Sumerians, Babylonians, Asyrians, Egyptians, Harrappan and Chinese) around 4000 to 5000 BC (Hillel, D.J. 1991). Similar to water, importance of maintaining soil fertility was recognized by Mesopotamian and others since 2500 BC. The practice of manuring dates back to 900 to 700 BC and that of green manuring to 234 to 149 BC (Tisdale, S.L. and W.L. Nelson. 1966).

Soil affliction. Some ancient cultures "afflicted" fragile soils in a manner similar to a pathogen afflicting another organism (Hyams, E. 1952). In the case of fragile soils in harsh environments, such an interaction can lead to collapse of the human society and irreversible loss of the soil. The extinction of many ancient societies (e.g., the Mayan Kingdom in Guatemala) and widespread occurrence of degraded and depleted soils is attributed to this self-destructive interaction between humans and soils.

2.4 Soil functions and modern civilization

Modern civilizations, characterized by large populations and numerous demands and aspirations, cannot sustain themselves without a major behavioural change toward soil resources. Humans have to live with soil in a symbiotic relationship based on mutual enhancement, nurturing soil resources to improve their life-support systems, and restoring and rehabilitating degraded soils and ecosystems. The behavioural change (e.g. symbiotic, nurturing and restoring attitude) is necessary to realize all the functions of soil that are necessary to meet the demands and fulfil the aspirations of the rising global population.

Historically, soil has supported plant growth to provide for the basic necessities of life of human societies, namely in the form of food, feed, fibre and fuel. Recent advances in agronomic sciences have dramatically increased soils capacity to produce the needed biomass to meet the needs of increasing human population.

These advances include nutrient management technologies to achieve the desired biomass production, water management to optimize the soil moisture regime and create a favourable balance between liquid and gaseous phases, and soil physical manipulation through appropriate tillage methods to create a favourable balance among solid: liquid: gaseous phases and optimize porosity and pore size distribution. Soil is a major repository of germplasm and contains a vast gene pool of flora and fauna. In addition to food production and as a substrate (medi-

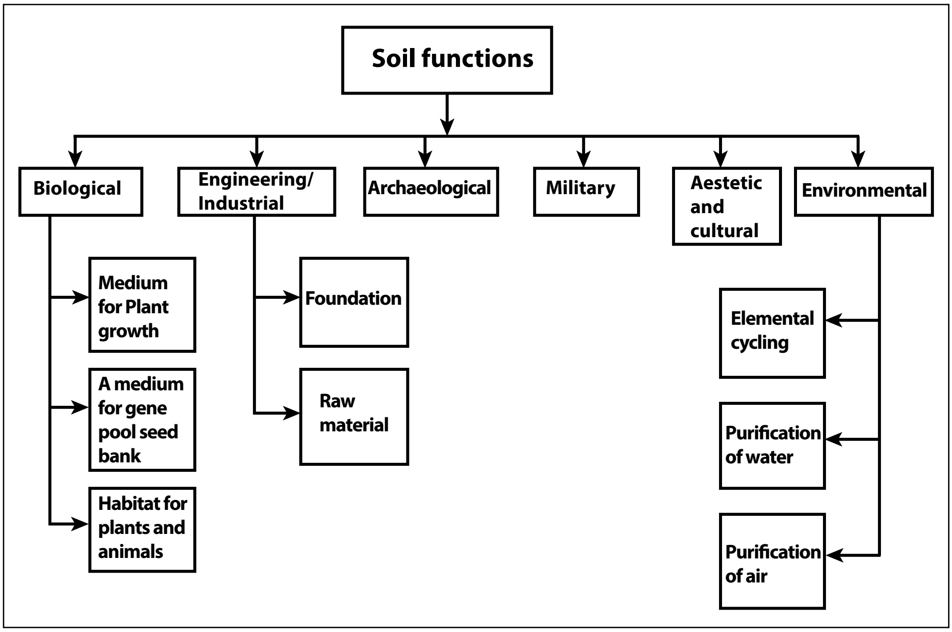

Figure 2.4. Soil functions of importance to humans and modern civilizations

um) for plant growth, soil has numerous other functions of importance to modern civilization (Yaalon, D.H. and R.W. Arnold. 2000).

Soil serves as a geomembrane to denature, filter and buffer against natural and anthropogenic pollutants, thereby moderating quality of natural waters. Depending on land use and management, soil also serves as a repository of C, N and other elements, influences the fluxes of these and other compounds between soil and the atmosphere, and moderates the gaseous composition of trace gases and particulate materials in the atmosphere. Soil is a habitat for flora and fauna (macro, meso and micro), and biotic transformations of organic matter returned to the soil are essential to its ability to perform functions. Soils also have numerous industrial/engineering uses including as a foundation for engineering structure, construction material and as raw material for industrial products (e.g., ceramic, brick-making and as a source of minerals). There are also cultural, archaeological and aesthetic functions of soil. The demand on soil resources continue to increase with increase in human population, and rising aspirations of human society (see Figure 2.4). In addition to producer of food, soils function as an environment moderator because industrial/engineering raw materials are likely to increase.

2.5 Soil processes

Soil is a vast reactor and a medium for numerous biochemical and physical transformations. There are numerous processes or reactions that influence the quality of soil and govern its capacity to perform the necessary functions (Figure 2.5). Important physical processes include erosion, illuviation/eluviation, gaseous exchange via diffusion and mass flow, and infiltration and percolation of water and solutes into and through the soil body. Soil physical processes influence evolution of landscape and fluxes of water, solutes and gases through the soil-plant-atmosphere continuum.

Interacting with physical processes are chemical reactions that alter soil reaction, solubility and uptake of elements by plant roots, and movement/accumulation of chemicals in soil column. Notable chemical processes are solubilisation, oxidation/reduction, salinization and alkalization. Chemical reactions and transformations govern the availability and uptake of nutrients by plant roots. Biological processes are important to transformation of organic matter into simple inorganic compounds and complex humic substances.

The study of these processes and transformations constitute specific branches of soil science including soil physics, soil chemistry and fertility, and soil microbiology and biochemistry. The branch of soil science dealing with soil forming processes, genesis and classification is called pedology. These specialized studies of soil science involve close interaction with other scientific disciplines to understand complex interactions between soil and the environments (Figure 2.6). The present and future needs of society can only be met through an inter-disciplinary

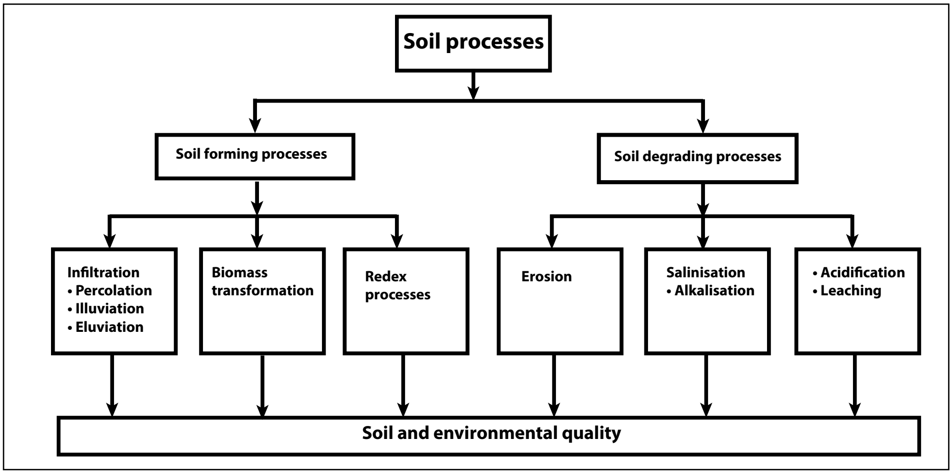

Figure 2.5. Soil physical, chemical and biological processes that govern soil quality and moderate soil functions

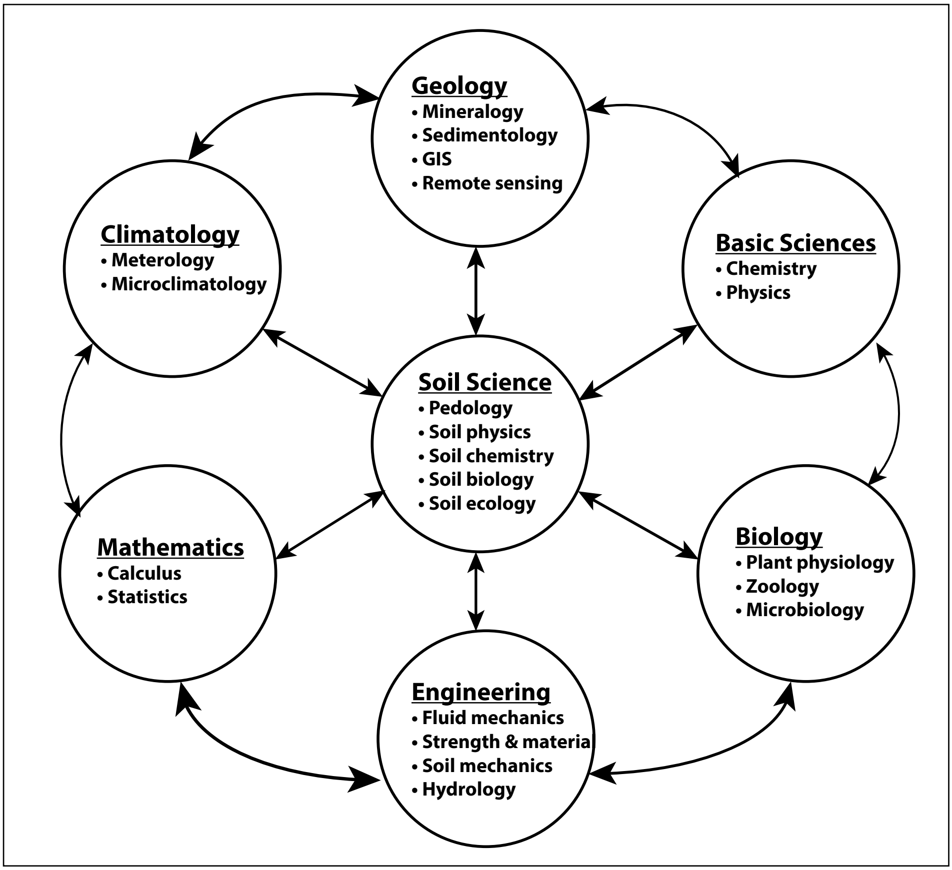

Figure 2.6. A complete study of soil involves close inter action with basic sciences and engineering In addition to properties and processes that govern soil quality, there are other soil attributes that must be understood to develop strategies for sustainable management.

and holistic approach to understanding properties and processes in soil that affect biomass production and environment quality.

A complete study of soil involves close interaction with basic sciences and engineering In addition to properties and processes that govern soil quality, there are other soil attributes that must be understood to develop strategies for sustainable management. Important among these are the following:

- World soil resources are finite, especially soils of good quality with few or no limitations for an intensive and continuous use.
- Total land area of the earth is 13 billion hectares (Bha) of which the cultivable land is merely 11% or 1.44 Bha.

- Land suitable for use as permanent meadows and pastures constitute 26% (3.36 Bha), and that for forest and woodlands about 30% (3.89 Bha) (Engelman, R. and P. LeRoy, 1995.).
- Large areas of land are unsuitable for cultivation due to climates that are too cold (permanently frozen) or too hot (desert), barren lands (eroded, salinized) or terrain that is too steep and unfit to cultivate.

Source for chapter 2

Sections 2.1-2.5 Adapted from: Lal, R., 2002: *Soil its life support systems and subject of improvement* in "Agricultural land improvement: Amelioration and reclamation Vol I", UNESCO, EOLSS Publishers, Oxford, UK.

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Chapter 3
The Science of Agricultural Reclamation

3.1 Why land reclamation

The factors restricting productivity of soils and plants are as follows:

- excess moisture content in the root layer of the soil;
- poor aeration of the root layer;
- excess acidity;
- poor availability of moisture in the root layer;
- low soil moisture;
- low content of humus and available nutrients;
- thermal regime unfavourable for the crop species;
- salinization of soil;
- pollution;
- unfavourable physical-mechanical properties of soil.

Reclamation measures can be considered as systems for regulating environmental conditions for the purpose of creating optimal conditions for growth and development of biotic assemblage, particularly for agricultural plants. The motivation for development of modern systems of agricultural reclamation comes from the conflict between the practically unlimited needs of developing humankind and our restricted ability to use natural and human-made resources. Methods of reclamation is described in chapter 1, table 1.1

As a result of evolution, the ancestors of modern plants developed in such a way that conditions in their places of origin became ecologically optimal for each species. Humans increased the productivity of natural species through cultivation and artificial selection, but their tolerance of changing environmental conditions, which was a peculiar feature of every species, was reduced. In the course of human migration from one region to another, plants were transferred to terrain with essentially different, and less optimal, natural conditions for each species. At the same time, in the process of economic activity, humans significantly changed their local environment – a process which had a negative impact on native plants.

In this situation, the balance between the structural-functional adaptations of plants and their environment was disturbed. The time necessary for evolutionary acclimatization of plants, far exceeds the time of their exposure to the new and the changed conditions. Humankind was forced to seek a radical improvement of environmental conditions, both to maintain the growth and development of agricultural plants, and to restore natural conditions in the disturbed areas. Thus, the need for creating optimal conditions for agricultural plants and restoration of natural ecosystems stems from incompatibility between the requirements of plants (autotrophic part of the ecosystem) and the environmental conditions. In future, we can expect human activity, of all sorts, to be increasingly incompatible with natural biological systems.

Humans selected and developed extremely productive plants, and these have replaced natural communities over very large areas. Their productivity is 50–100 times that of their remote ancestors. But a consequence of this high productivity is the reduction of natural acclimatization (3-5 times). Certain factors, which may be small in absolute magnitude (e.g. trace elements, micro-doses of toxic gases, etc.), become limiting at the optimal level of the others, and begin to exert a significant influence on productivity. From a minor level of disturbance to the ecosystem, the maintenance of a stable state becomes impossible without precise adjustment of a complex of environmental factors.

3.2 Principles of land reclamation – the nine stages approach

The principles and requirements for a system of complex regulation for production of autotrophs can be formulated as follows:

- Maximum utilization of insolation and photosynthesis of active radiation (PAR) by the crops – this is a key and underlying criterion;
- All factors are regulated actively and purposefully;
- At every moment of growth and development of plants, the value of the limiting factor is adjusted to a level within the optimal range;
- Optimal conditions are created at the critical moments for growth and development of plants;
- The error of adjustment should be significantly less than the width of the optimal range of acclimatization of a plant;
- Priority should be given to providing optimal conditions for the growth and development of the plant species which is in the most depressed state;
- For normal operation of a system of complex regulation, the stochastic heterogeneity of soil properties and nutrient stocks, and non-uniformity of natural fertility in the catchment, should be taken into consideration.

- For creation of a naturally-restoring system, it is necessary to achieve not only high productivity of plants, but also increasing fertility of the land;
- Ecological safety must be ensured by building closed cycles with re-generation of energy and matter flows in adjoining ecosystems up to the natural level.

To solve all the relevant problems through the regulating process, it is necessary to have a quantitative expression of the requirements of plants (and biota in general), and the environmental conditions. Later on, knowing to what extent environmental conditions do not correspond to the requirements of biota, it is possible to determine the minimum influence necessary to achieve the desired result.

After evaluation of the necessary regulating actions, selection of the executive devices corresponding to each adjusted factor can be made. The next stage is synthesis and integration of the devices for regulating the aqueous, thermal and nutrient conditions. The development cycles of methods of complex reclamation and regulation can be displayed by the scheme proposed by Shabanov, V.V. (1973, 1981) *in stages*, as follows:

3.3 Stages 1-4 – identifying the factors required

Stage 1. The requirements of plants, and subsequently, of any living organism, to environmental conditions according to a number of macro-factors (water - S_w and thermal S_t conditions, mineral nutriment and gas nutriment S_f , solar energy S_r) and micro-factors (trace elements and micro-concentration of gases) are explored (first stage). In this case, the requirements of living organisms are seen as a quantitative interrelation showing their change of productivity in relation to environmental conditions and anthropogenic action. For the purposes of regulating, it is necessary that the requirements of plants and microorganisms are expressed as quantitative dependence, i.e. the corresponding mathematical models must be developed. Thus, understanding of the general mechanism of interaction of a plant with its medium, and construction of theoretical models, has to be considered the first objective.

Stage 2. Study of the mechanism of formation of environmental conditions and the quantitative expression of these processes forms the second group of mathematical models. First it is necessary to solve the problem of mathematical description of environmental conditions. The form of this description should reflect in the best way the essence and nature of the circumscribed magnitude (second stage). The descriptions can be split into determined and probabilistic ones. It is known that meteorological processes, which are ultimately controlled by solar activity, are random in time. It is these processes which determine precipitation, temperature, wind and other environmental conditions. Therefore, probabilistic, or stochastic, description should be adequate for describing environmental conditions.

However, it is possible to express the mechanism of generating aqueous $W_{(x, y, t)}$, thermal $T_{(x, y, t)}$ and nutrient conditions $F_{(x, y, t)}$ at every point in space by determined differential equations that are widely used today. Applying to them the law of distribution of probabilities of conductivity coefficients, it is possible to obtain the stochastic mechanism of generation of environmental conditions and thereby to connect the stochastic and determined methods of description of environmental conditions.

Stage 3. The research in the first two stages can be generalized *in this third stage* in the form of an indicator of the need for reclamation/amelioration measures. This indicator is based on information on the requirements of living organisms and the prevailing environmental conditions, i.e. the probability is reflected of optimal (P_w, P_t , P_f) or non-optimal P ($\overline{P}_w$, $\overline{P}_t$, $\overline{P}_f$) requirements for a plant in a specified geographical region. In a certain sense this parameter can be termed bioclimatic. Thus, the features of soil-generating processes, which are the most important for substantiation of nature protection measures, are manifested in aqueous, thermal and nutrient conditions of bedrock and soil.

Depending on the initial information used for describing the environment (and on the stage of development), the indicator of need for action reflects either the general geographical conditions if it is based on climatic data, or the microclimatic conditions of marshes, irrigated areas or other kinds of land. The climatic indicator can be used for determining the directions of nature management and environmental engineering over vast areas, and also for planning the lay-out of engineering works and energy expenditures for creation of the optimal conditions. The microclimatic indicator of necessity for regulating action is applied to a discrete area of land. It is possible to obtain these parameters, using mathematical models.

Thus, evaluation of probability of optimal or non-optimal requirements is the subject of the third stage of the decision-making process. It is necessary to note, that determining need in environmental factor management can be either single-factor, or multifactor. The probability of non-optimal aqueous $\overline{P}_w$ or thermal $P_{\overline{t}}$ conditions is calculated in the first case, and in the second case non-optimal aqueous, thermal, nutrient and radiation requirements ($\overline{P}_{w, t, c, f, r}$) are calculated.

Stage 4. The maximal range of regulation of environmental conditions is determined for every factor (D_{max}.). All the probable deviations of environmental conditions from the optimal, are included within this. The maximal range of regulating determines the limits of the regulating system and is used in this fourth stage of its development.

3.4 Stages 5-7 – engineering the process

Stage 5. Operative control of the regulating process plays an important role – the calculation of this constitutes the subject of this fifth stage. This involves a measure of prediction, i.e. the difference between the requirements of plants, or other biota, and the predicted magnitude of external factors should be continuously calculated. Therefore the main problem for research at this stage is the development of methods of prognosis of controlled magnitudes and calculation of control actions for each factor (Δw, Δt, Δc, Δf, Δr), with allowance for their interaction.

Stage 6. This sixth stage involves the solution of a number of problems related to engineering realization of the desired aqueous, thermal and nutrient conditions, including the problems of automation of processes of complex regulating. The calculation of regulating systems can be realized only where there is knowledge of the mechanism of nutrition, water and heat dissipation from the executive element to the plants. Since the medium, in which this occurs is of a complex stochastic geometry, the mechanisms of water, heat and nutrition dynamics are not yet developed in many respects. Therefore, the study of how water, heat and nutrients move from an executive element to the plants, together with the change of soil properties under the influence of water and solutions, is one of the research problems of the sixth stage. Based on this, it is necessary to decide, what the time lag can be for various types of regulating devices and methods, and the optimal distribution of regulators over the terrain, with allowance for its spatial heterogeneity.

Stage 7. The regulating of a single factor can be realized in many ways, but it is a lot more difficult to keep a number of factors at an optimal level. Therefore, in the seventh stage the problem of optimization of regulators, both single-factor, and multifactor has to be solved. First of all, the criteria of optimization, depending on the problems faced in the regulating, should be defined. Then it is necessary to choose mathematical methods which are most convenient for solution of the specified problems. However, it is necessary to take into account, that the optimal single-factor systems might be non-optimal when working in a complex of factors, so it is necessary to search for multi-parameter optimality criteria. Apparently, some optimality criteria have an economic structure. This circumstance makes it necessary to study some technological parameters and economic links.

Thus, this stage provides the calculations necessary for the reclamation system to restore or maintain the desired equilibrium in growing conditions.

3.5 Stages 8-9 – computer-aided design

Stage 8. Nevertheless, it would be wasteful not to use information obtained from a single object, if it can be applied for similar development of other objects. In this case, extrapolating the results is impossible if there is no certainty of the level of basic properties of the considered objects. Certainty can be assured only on the basis of quantitative assessment of similarity of the objects. Such assessment can be expressed in the form of quantitative multi-parameter classification of natural objects.

These problems are explored in this eighth stage. Here a number of problems appear, the solutions for which are only just beginning to arrive. It includes the problem of integration of multi-parameter data and their representation in a form convenient for making calculations, the problem of definition of class patterns, the problem of choice of criteria of affiliation with the class, and a number of others. Furthermore, at this stage, the computing programming problems are very important, as some multi-factor algorithms can only be run with the help of a computer.

Stage 9. The ninth and final stage of the research includes the development of methods of computer-aided design, which can be accomplished, for example, by searching for the optimal variant of regulating for the objects of each class. Let us consider the third stage of the research in more detail.

According to the aforesaid, this stage is a generalization of the requirements of plants and environmental conditions in the study area. If the requirements of the plants and the soil conditions coincide as regards the major factors (aqueous, thermal, radiation and mineral nutrition), then the natural/anthropogenic system is in a stable state and no measures are necessary for its maintenance. However, in view the stochastic character of environmental conditions, it is more expedient to determine the requirements of plants as a probability of occurrence of non-optimal environmental conditions both against every factor, and against a set of all factors.

This probability can be calculated repeatedly during the period of growth and development of plants, for example, once every ten or five days. If the probability of optimal conditions is great (P_{opt}> 0.7-0.8), a reclamation system aimed at correcting environmental conditions is not required. If the probability of non-optimal conditions is great, it is necessary to provide control actions, to restore optimality. Thus, the considered operation in the indicated form combines data on the requirements of plants and environmental conditions into one parameter.

Depending on the materials initially used to describe the environment, this parameter will reflect either the general geographical mechanism, if it is calculated on the basis of macro- and meso-climatic data, or a microclimatic mechanism related to drained marshes, irrigated terrain or other kinds of reclaimed land. The climatic parameter of reclamation requirements is applied for definition of the general direction of reclamation work. It can be used for planning of allocation of reclamation zones and assessment of energy expenditure for generation of optimal conditions. The microclimatic parameter, on the other hand, is applied for planning the reclamation actions, i.e. for detailed calculation of the regulating system.

3.6 Is there a single parameter of reclamation?

We shall consider the procedure of evaluation of the statistical parameters of reclamation requirements. From the mathematical point of view, this problem is set as follows: to determine the probability of occurrence of non-optimal environmental conditions for a plant, if the environmental requirements of the plant and the environmental conditions are known and expressed in the form of distributive laws of aleatory (unpredictable) variables or random functions of environmental factors.

The distributive laws can be obtained from solution of stochastic differential equations, or they are defined on the basis of perennial observations. The solution of the set problem is obtained in the form of probabilities of necessity (requirement) of reclamation − $\overline{P}$. The probability is repeatedly calculated throughout the period of vegetation, for example once every ten days. This allows the evaluation of need for reclamation actions every ten days. If the probability of non-optimal requirements is great: $\overline{P} \geq 0.6$, it is necessary to provide for reclamation actions, the probability of which will be equal to the probability of the non-optimal requirements. Thus, the substantiation of reclamation requirements of the indicated kind combines the data on the requirements of plants and environmental conditions into one parameter.

What requirements should the parameter of reclamation need correspond to? The parameter should completely reflect the requirements of plants in relation to environmental factors. It should completely reflect the environmental conditions, in particular the stochastic nature of soil factors. It should be constructed on the basis of environmental factors which can be controlled. For example, the aqueous factor can be expressed as moisture content in a particular layer of soil, so that it is simple to calculate the system supporting this moisture content within the optimal range. The calculated period, for which the parameter of reclamation need is calculated, should be short enough to assess a change of the parameter during the whole period of vegetation. It allows the marking of critical periods in which particular kinds of reclamation are given higher priority.

The parameters of reclamation of each factors should be generated successively so that a single-factor parameter is a special case of a two-factor parameter, and the last one is a special case of a three-factor parameter, etc. The parameter of reclamation need should have a clear physical sense. For example, it should allow determination of the frequency of this or that kind of reclamation required for a specified object.

3.7 Kinds of land reclamation

Regulation of the water, thermal, nutrient and other conditions on reclaimed land can be accomplished by many means. Surplus moisture is controlled by drainage of land, and lack of water by irrigation. Surplus of chlorides is controlled by desalination (flushing the soil with fresh water and removal of saline water through drainage). Shortage in the soil of such substances as nitrogen, phosphorus, potassium and others is controlled by supplying fertilizer, either in solid or liquid form. Soil temperature can be adjusted by mulching the soil or through irrigation with sprayed water.

Reclamation systems accomplishing the regulating of conditions against many environmental factors can be called systems of complex reclamation regulation. Such systems are most effective within the frameworks of adaptive landscape agriculture.

Complex reclamation regulation within the framework of a system of adaptive landscape agriculture consists of the following:

- Creation of water, thermal and nutrient conditions of soils, to promote: the reduction soil compaction (regulating the terms of spring “maturing” of the soil, regulating the consolidation of soil through optimal control of groundwater, etc.);
- Achieving greater efficacy of recycling of organic sources of nitrogen and use of organic fertilizers;
- Optimization of ion exchange and microbiologic activity;
- Maintenance of populations of the natural enemies of pests;
- Depressing the sources of plant diseases;

- Reducing soil erosion and leaching of chemical elements into groundwater.
- Locating agricultural crops with due regard for the landscape (exposure on hillsides, slopes, and geomorphology).
- Optimization of water, nutrient and thermal conditions of soils for each crop of the crop rotation, promoting the maximum use of the adaptive abilities of agricultural crops.

In alternative agriculture, soil nitrogen is managed by application of manure and composted plant material or 'green manure'. These techniques are gradually replacing inorganic nitrogenous fertilizers. In the system of complex reclamation regulating these measures produce the following effects:

- Reduction of denitrification by leaching and evaporation;
- Reduction of nitrogen waste through its consumption by weeds; this works if the program is applied correctly, (i.e. the nutrient elements are applied at the right time, close to the time of maximal consumption by the crop plants), and is most effective with the help of sprinkling and sprinkling irrigation systems;
- Slowing down the process of mineralization of organic elements in soil through active control of aqueous and thermal conditions and satisfaction of the long-term nutrient requirements of plants;
- Regeneration of organic elements of soil, its structure, ion exchange capacity and microbiological activity.

3.8 raising soil fertility

The program of raising soil fertility cannot be separated from the scheme of crop rotation. Crop rotations are necessary because they allow crop plants to absorb the nutrients left behind by the previous crop, and, besides, integumentary crops are able to bind soil nitrogen, which prevents leaching and allows it to be released slowly over a longer period, as the plants decompose.

Appropriate choice of crops in a rotation extends the effectiveness of systems of complex reclamation regulation, as these systems create more varied environmental conditions, optimal for different plants. Quantitative description of change of productivity, as a dependency on environmental factors, can be described in many ways. The simplest form of mathematical model of a plant-environment system was proposed by Shabanov V.V. On the basis of experimental research and theoretical generalization, general dependencies were obtained between environmental conditions and productivity of plants. The different stages of crop production are relevant parameters of these models.

A similar approach can be used for description of soil biota or biotic of elements of water bodies. Depending on which factor is limiting, i.e. constraining the growth and development of a plant, the land reclamation technologies can be selected. First of all, the conditions under the first limiting factor are improved, then those under the second factor, etc., and the process continues until crop productivity reaches the necessary level. Applying optimal hydro-thermal conditions not only for agricultural plants, but for biotic constituents of the soil, it is possible to make up the loss of organic matter in the humus horizon. The humus horizon is the layer of soil with the highest content of organic matter (usually 0-20 cm).

Humus is part of the organic matter of soil. The contents of humus in the basic types of soils (according to I.V. Tyurin) varies from 2 to 12%, as follows:

- podzolic soil – 2-4%;
- gray forest podzolic soil - 4-6%;
- chernozem: southern - 4-6%, ordinary – 6-8%, leached – 7-8%, potent – 10-12%;
- dark-chestnut soil – 3-4%;
- desert soil - 1-2%;
- red-earth – 5-7%.

Between 600 and 700 kg of humus are mineralized annually per hectare in dernovo-podzolic soils. As for chernozem, the process involves about 1000 kg per hectare. These figures represent 1% and 0.5% of the total of organic matter, respectively. Mineral compounds of nitrogen are formed in the process of mineralization, and these are accessible to plants. In order to obtain 1 part of nitrogen. The role of various elements of nutrition in the life of plants is very important. So, for example, nitrogen is a constituent part of all amino-acids, proteins, nucleic acids, chlorophyll, and other organic compounds in plants. Phosphorus enters the structure of nuclear albumens (nucleoproteins), and potassium promotes progression of carbohydrates from leaves into other parts of plants, and strongly influences the water-filling of vegetative colloids. If the element of mineral nutrition is a limiting factor, methods of regulation of nutrition mode are applied.

However, the efficiency of use of improved lands can be significantly decreased if there is a danger of soil erosion, if the level of natural land drainage is insufficient, if soil hydraulic properties are unfavorable, if the soils are clogged with stones, if agricultural holdings are overgrown with shrubs, and if agricultural holdings are subject to flooding and inundation

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Chapter 4
Drainage of Farmlands

4.1 Introduction

The anthropogenic development of land in many areas is intimately connected with the discharge of excess water. The use of land for different purposes aggravates drainage problems due to leakage of water from pipes, irrigation, waterlogging induced by artificial ponds and water storage basins, road construction, and deforestation that reduces natural drainage capacity. The design of drainage systems requires profound knowledge of topographic, soil, hydrologic, hydrogeological, economic, and socioeconomic conditions. Special surveys are required to select the type of drainage system, character of water collectors, kinds of drains, and design parameters of the network. Special agro-meliorative measures to accelerate runoff discharge and enhance the infiltration properties of soils are widely applied. Calculation of the parameters of a drainage system should take into account the optimal drainage regime required for a particular type of land management. The design of drainage systems is supported by solid scientific knowledge, including mathematical models based on theoretical and half-empirical equations.

Mathematical modelling is a rapidly developing branch of land reclamation science. Where capacious water collectors ensuring the self-flowing discharge of water from irrigated lands are not available, pumping stations and artificial levees embanking the drainage area are constructed. These systems are called polders.

Regulation of river flows by straightening and deepening them has virtually stopped because of environmental damage. In areas with unstable precipitation regimes, drainage-irrigation systems are constructed to discharge excess water during wet periods, store water in ponds, and supply additional water during dry periods. Artificial ponds supply water for irrigation, improve wildlife habitats, and have recreational and aesthetic values. Land drainage is generally accompanied by measures of land improvement, including the removal of shrubs, stumps, stones, and soon; land planning, and application of soil amendments and fertilizers. Drainage and soil amelioration techniques are fundamental to efficient agriculture and the preservation of biodiversity.

4.2 The history of land drainage

Land drainage for agricultural and other purposes has a long history. The first works on land drainage, along with irrigation, were conducted about 4,000-5,000 years ago in the flood plain of the Nile in Ancient Egypt, and in ancient China. Extensive systems for the drainage of bogs and fens were constructed by the ancient Romans, and there is abundant evidence of their expertise in all forms of water control, including large-scale field drainage. This can be illustrated by the example of southeast England, where the drainage of fens was started by Roman soldiers in order to provide the army with foodstuffs. There is little doubt that the Romans carried out the first reclamation works in areas like the Fens and Romney Marsh, and, although there is no evidence of piped field drainage, this reclamation must have included some form of infield water control.

After the Romans departed, the drainage works like their roads were allowed to fall into neglect, and it was not until after the Normans had established their rule in the eleventh century that interest in drainage was reawakened. During the twelfth century, Thomas à Becket continued the reclamation work started by the Romans. This was to have great significance in that Henry III confirmed the Charter of Romney Marsh (1252), which laid the basis for land drainage in various parts of the country for centuries to follow.

In the seventeenth century a leading figure was Cornelius Vermuden, a Dutch engineer demand for food. With encouragement from Church and State, drainage activity was renewed not only in lowland areas, but also on higher ground where agricultural production was being intensified. By 1846, land drainage had become recognized as a national asset and, by Act of Parliament, the Government made available large sums of money for drainage improvement. The Act enabled companies such as the General Land Improvement Company to be formed to finance drainage works. Open channels remained the main drainage method. Closed drains were built of fascines and stones until the early nineteenth century, when drains made of clay were developed. The revolution in drainage construction dates back to 1845, when Thomas Seragg invented an extruding machine that produced round clay pipes quickly, reducing cost.

For the next century, ceramic (tile) pipes became the basic means of drainage in all countries. The experience in land drainage gained in England deserves special study. Virtually all waterlogged land has been drained and is successfully used for crop growing. The thermal regime of drained land has also been improved, making it possible to grow up not only traditional but also heat-loving crops (sugar beet) and orchards. The creation of polder systems in the Netherlands and Germany is another amazing example of efficient drainage.

By the second half of the nineteenth century, the main works on land drainage were almost complete in Belgium, the Netherlands, Germany, Italy, Denmark, and a number of other countries. Virtually all waterlogged lands with agricultural potential had been drained. Since these achievements, for more than a century, the focus of attention has been upon reconstruction and modernization of drainage systems, which has been accompanied by evident changes in the whole landscape.

The total area of drained lands in the world is estimated at 1.8-2 million km^2 (180-200 million hectares); about two-thirds of these are in Europe and North America, including 0.6 million km^2 of drained lands in the United States. The area of drained lands in Asia is about 0.5 million km^2. The twentieth century brought considerable changes to the technology of drainage works. Open channels and ceramic tubes have been replaced by plastic tubes.

4.3 What area will be affected by the drainage system?

The long-term forecast of drainage-induced changes in the environment presents certain difficulties; it is complicated by the need to assess these changes from the economic viewpoint. The environmental impacts of a drainage system can be subdivided into direct and indirect effects. Direct impacts are related to the removal of excess water from the fields and intensification of agricultural production on them. Indirect impacts are related to changes in the environment within the drainage system and in neighbouring territories. They may have both positive and negative aspects. Positive indirect impacts manifest themselves in changes in plant communities that increase biodiversity. Negative impacts result from the action of numerous factors that are often barely predictable and appear quite unexpectedly.

The main factors that change under the impact of drainage are: the discharge and water level in local streams, the total reserves of surface and ground water in the area, groundwater level, evapotranspiration, soil temperature regime, the character of pedogenesis (especially, during the drainage of peat bogs), and the species composition of local flora and fauna.

The drainage of bogs and waterlogged territories inevitably leads to a lowering of the groundwater level and considerable redistribution of water. This is the leading factor controlling all the other changes in drained areas. Some factors change considerably; others remain relatively stable. The degree of changes depends on local environmental conditions. Thus, in humid regions, drainage systems cause significant changes in the temperature regime of soil and aboveground air.

This factor is of primary importance for agricultural production. The character of changes also depends on the scale of the drainage system, in particular on the proportion of drained land in the total catchment area. Both positive and negative consequences of drainage should be properly assessed in economic terms, in particular the repayment time of capital investments in the drainage system.

The goal of a drainage project is not just to ensure the maximum gain in yield at large water reservoirs constructed on the rivers, and to irrigation systems. The need for drainage depends on the level of economic development reflected in the degree of intensification of agriculture and crop yields. The main drainage objects are river valleys and waterlogged mineral lands, as well as fen bogs. They all have a natural water regime unfavourable to farming: backwater, increased soil moisture content, and shallow groundwater.

4.4 Categories of waterlogged lands

Waterlogged lands are classified into two categories according to the duration of waterlogging: permanently waterlogged lands (bogs, flooded lands, low alluvial plains, coastal lowlands, etc.) and temporarily waterlogged lands. Permanently waterlogged lands are unsuitable for agriculture, although low yields of poor wild grasses can be obtained on them during some dry seasons. Temporarily waterlogged lands pose a risk for agricultural production, because crops cannot be grown or harvested in some wet seasons.

Permanently waterlogged lands are subdivided into peat lands, boggy soils, and mineral soils. The main criterion for their separation is the thickness of the peat layer (m) after drainage: peat lands have a layer of more than 0.3 m, while in boggy soils the layer is less than 0.30 m. In mineral waterlogged soils, there is no peat layer. Bogs are subdivided by the topographic position and the kind of peat into low (eutrophic), transitional (mesotrophic), and high (oligotrophic) bogs. Lowmoor bogs and mineral soils are the main objects of agricultural amelioration. Peats comprise soils with an ash content less than 50-75% of the dry matter weight; they can be subdivided into low-ash (<10%), medium-ash, and high-ash peats (> 20%).

The ash content in peat material depends on the species composition of peat-forming plants and the geochemical interrelations of a bog with adjacent territories. It has a zonal character, increasing in a meridional direction from north to south (in the northern hemisphere) in parallel to an increase in the erosion intensity and the salt content of the ground water. The high-ash peats have the highest value.

The distribution of bogs and boggy lands also has a zonal character: their area decreases from the northern agricultural boundary to the south. Climate is the main factor responsible for waterlogging: bogs develop in conditions of permanent or periodical dominance of atmospheric precipitation over evaporation. Waterlogged mineral soils are characterized by the presence of reduced zones (gley features) at different depths (gleyed or gleyic soils).

The degree of soil waterlogging also depends on other factors: geological conditions (the soils of large tectonic depressions are more susceptible to waterlogging), relief conditions (the degree of ruggedness of the topography, slope degree, etc.), the character of parent rocks (water permeability and water yield capacity), hydrogeological conditions (the groundwater depth), natural drainage conditions (density and depth of the river system), and roughness of the soil surface, among other factors.

Soil waterlogging can also be caused by anthropogenic factors (the construction of reservoirs and land flooding, the elevation of groundwater table because of excessive water expenditure for irrigation, infiltration water losses from channels, etc.). The reasons for soil waterlogging should be determined clearly before the development of reclamation projects.

Land drainage and flood control works are performed on about 3 million km^2 (300 million hectares) around the world. These works generally affect the interests of various stakeholders. It is often necessary in drainage work for farmers to work together to accomplish their common goal: improved land drainage leading to sustainable farming. Drainage enterprise can be organized on the basis of voluntary or cooperative groups, legal organizations, drainage associations, informal drainage groups, and so on. Each of these has particular advantages and disadvantages; the choice of the most suitable form of drainage enterprise depends on local conditions. The majority of drainage works in European countries (the UK, Belgium, Germany, Italy, Russia, etc.) have been performed on the basis of drainage associations and legal drainage groups. State support of drainage works is primarily connected with control of the efficiency of drainage systems, the design of projects, and quality control.

4.5 Types of soil water supply

The type of soil water supply determines the reasons for waterlogging and the main sources of excess moisture; it reflects climatic, geological, hydrogeological, geomorphic, soil, and other conditions. Five main types of soil water supply can be distinguished: atmospheric, ground, ground head, deluvial, and alluvial. There may be several types of water supply (or a mixed water supply) within a single area. In this case, the main type of water supply should be determined on the basis of water budget calculations for soil layers from the soil surface to either the lower boundary of the root layer, or the groundwater table, or the aquifer. The main types of hydrogeological conditions in waterlogged areas are displayed in Figure 4.1.

Abundant water supply is characteristic of bogs developing in areas of ground water discharge to the surface through head-water springs. An equation for the groundwater balance or the water balance in the aeration zone can be used to determine the most important component of the water regime of a drained soil:

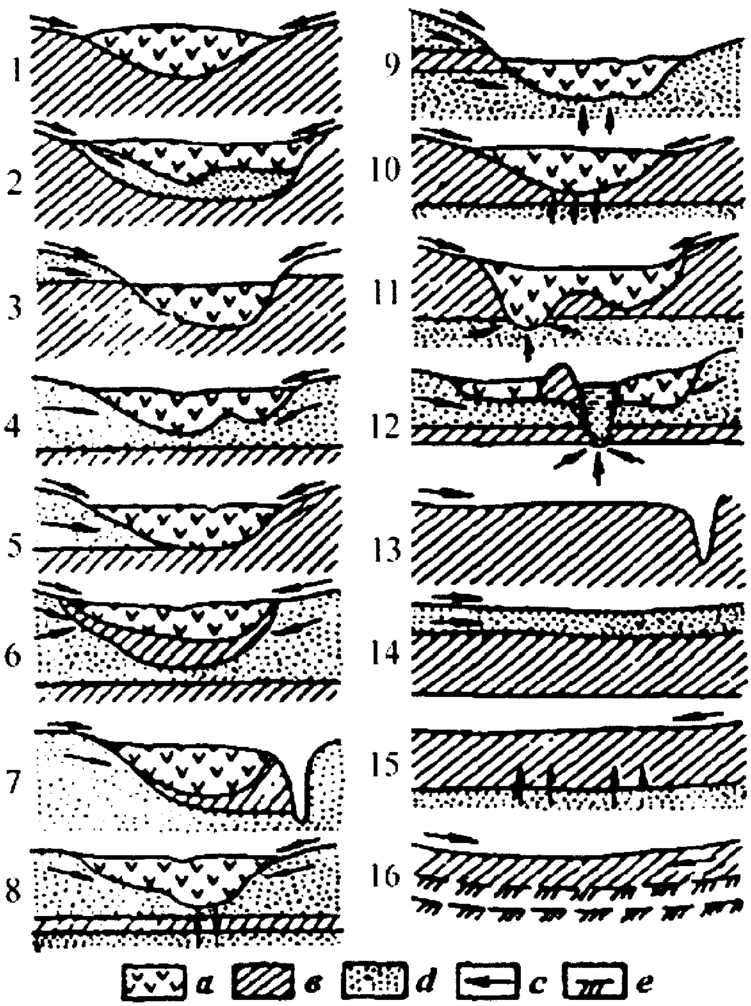

Figure 4.1. The main types of hydrogeological conditions in waterlogged areas (Maslov, 2002)

the groundwater exchange rate and its recharge of the root layer. The value of water exchange between the groundwater and the aeration zone, e.g. changes at different seasons of the year: groundwater accumulates during periods of rains, whereas in dry periods groundwater recharges the root layer.

The water influx into the root zone is inversely proportional to the depth of groundwater. The main input element of the water budget in waterlogged soils is atmospheric precipitation, and the main output item is evaporation. The role of groundwater reaches its maximum in back swamps. To solve the water budget equation, data on precipitation and condensation (the latter is often negligible) obtained at meteorological stations, together with the results of hydrogeological (influx and deflux of groundwater), hydrological, and soil studies, are used. Drainage procedures are mainly aimed at increasing the output items of the water budget, though it possible to regulate both input and output items of the water budget in order to maintain optimum moisture status in soils.

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Chapter 5
Phytomelioration

5.1 Introduction

Two interconnected phenomena have provided preconditions for phytomelioration throughout much of the world. These are increase in land degradation and shortage of foodstuffs for the growing human population. Ill-considered expansion of arable land, and irrational use of water and ground resources has resulted in losses of huge areas of fertile land.

Alongside other kinds of land improvement, phytomelioration plays a valuable role as a system of measures for improvement of environmental conditions. This relies on the beneficial influence of plants on the condition of soil cover, water resources, air and other factors of the natural environment. Phytomelioration can reduce or completely eliminate such negative processes as erosion by water and wind. It is used in stabilization of ravines and mobile sand, and improvement of degraded pastures. Protection of irrigated and drained land is often achieved with the help of phytomelioration. It is thus one of the key factors in stabilization of agricultural land.

The term phytomelioration covers a complex of actions for improvement of the natural environment with the help of a cultivation or maintenance of natural vegetative communities (e.g. creation of forest belts, field edge plantings, undersowing of grasses, etc.). The different kinds of phytomelioration include: humanitarian (improvement of the human environment), interior (within premises), nature conservation (preservation and improvement of ecosystems and their components), bioproductive (increase of quantity and quality of useful production), resource-protective (preservation of habitats and species), and engineering (protection of property).

Programs of phytomelioration for degraded agro-landscapes in such countries as Israel and USA are based on solid achievements of plant breeding, genetics, and biotechnology. At the same time in Asian countries (e.g. China, Uzbekistan, Kazakhstan, Turkmenistan) programs of phytomelioration of arid agro-landscapes are based mainly on the use of the rich plant genetic resources of old grasslands, development of eco-evolutionary methods of selection, and creation of systems of geographically and ecologically differentiated communities of halophytes, xerophytes and psammophytes. Agro-technical methods of ecological restoration have also been developed, using a mixture of seeds of bushes, sub-shrubs and grasses. In Asian countries with arid climates, phytomelioration has transformed many agro-landscapes, mainly for production of fodder. The agro-phytocenoses created, containing bushes, sub-shrubs and grasses have proved to be both productive and self-perpetuating.

Phytomelioration is one component of the complex of measures used to combat drought-optimum combination of arable, meadow and woodland, creation of forest strips aligned against the prevailing winds, and afforestation of land not well suited to agriculture (e.g. woods, ravines, bare river margins, etc.) Two major components of phytomelioration of land are forest improvement and agro-forestry. Forest improvement is a directed change of environment by growing trees and shrubs (by creation of plantations and shelterbelts, change of age and species composition of trees and shrubs, and optimization of the ratio of wooded to non-wooded land.

Agro-forestry involves creation of field-protecting forest strips, and planting of trees on slopes of ravines, steep slopes and sandy ground. Its effectiveness depends on how well suited the lay-out of strips is to the local conditions and the character of those strips (height, permeability to wind etc.). The ratio of the areas of woodland to open fields is also very important.

5.2 Phytomelioration: the concept and sphere of application

Phytomelioration of land has become, both in theory and practice, a dominant concept in world agriculture and one of the most important tools of land amelioration. It is a means of achieving purposeful improvement of the natural environment, and reconstruction and development of biological potential of degraded land. Phytomelioration is a key element in stabilization of agriculture. Phytomelioration of degraded land relies on the natural potential of vegetation and reconstruction of soil fertility.

The kind of habitat created, and its rate of development, depends on the choice of plants, their life form, adaptations and ecological requirements. The adaptations of natural flora to widely varying ecological conditions and geographical areas – at the level of life forms, species, ecological types and populations – creates a wide spectrum of plants, providing a firm basis for selection of suitable phytomeliorants.

Phytomelioration as a science is based on the principle of restoration of the ecological potential for development of biocenoses. Since the early 1990s the wise use of the potential of higher plants (trees, bushes, sub-shrubs and grasses) to change environmental conditions and restore land potential has become fundamental to sustainable development of agriculture all over the world.

Habitat creation is best demonstrated at the biogeocenosis level. Lessons can be learned for controlled optimization of the ecological environment and the functional organization of agro-landscapes. Phytomelioration is often the only possible self-sustaining means of supporting the regenerative potential of degraded land.

Plants help to create and improve their environment by depositing onto the soil surface a layer of dead material which accumulates as a litter layer, from which soil humus develops, or, if conditions are wet enough, as a layer of peat. The products of decomposition of dead aerial and underground parts of plants increase the water-penetration and water-holding capacity of soils. It increases absorption of precipitation and reduces run-off. Organic debris retards surface flow, increases penetration and reduces erosion. The aerial parts of plants reduce retain both water and snow and reduce the rate of flow of melted snow, thereby also reducing washout of soil. As a result of reduction of the speed of flow of melt-water, sedimentation of particles occurs.

The habitat creation potential of plants, together with soil organisms (animals, mushrooms, *actinomycetes*, bacteria), raises the level of many biochemical and chemical processes, as well as cation exchange capacity and the rate of accumulation of humus in the soil.

The concept of phytomelioration is based on the ability that natural communities have to assimilate material and energy – to accumulate organic matter in soil and to recycle solar energy. This concept provides harmonious development and interaction of natural, biological, technogenic, economic and information factors. Phytomelioration is a major component of long-term ecologically balanced strategies for wildlife management directed at increasing the capacity of agro-phytocenoses and agro-ecosystems for maintenance of ecological equilibrium. This balance is reached by increase of the genetic variation of biological components (including cultivated and wild species, soil animals and micro-organisms).

Phytomelioration is always focused on increase of biological efficiency, stability and optimization of the structural and functional organization of agro-landscapes. It is thus a science, a technology and a branch of agriculture. As a science, phytomelioration systematizes the facts, has specific methods of research, encompasses experiments and reproduces the results of research. As a technology, phytomelioration is a system of ecologically-, biologically-and biotechnologically-proven methods and treatments directed at the reclaiming potential on all components of agro-biocenoses and agro-landscape—atmosphere, soil, micro-organisms, flora and fauna.

As a branch of agriculture, phytomelioration is a system of biotechnological and organizational measures directed at improvement of the meliorative condition of land, improvement of soil fertility, and optimization of the structural and functional organization of agro-landscapes.

5.3 Phytoclimatic zones

Phytoclimatic zones reflect the major geographic zones of the land surface. Starting from the north, the first phytozone is the tundra, then there is forest-tundra, then taiga, then deciduous forest, then the steppes, then deserts (the arid zone), then subtropical forest and finally tropical forest. Phytoclimatic zones are directly connected to soil zones. Each type of soil has a corresponding characteristic vegetation which, basically, should find wide application in phytomelioration within the relevant phytoclimatic zone. Each zone has its own particular kinds of plants, treatments and management methods for phytomelioration.

Our planet supports a huge variety of higher plants – more than 250,000 species. Through prolonged adaptation to natural-historical conditions and the geographical zones on the planet, they have formed distinct communities – phytocenoses – the natural vegetative layers of the biosphere and the primary source of life on Earth.

The evolution and development of plant life on Earth has produced a series of natural regions, each with their own suite of species The flora of Russia totals more than 15,000 species; South America has 56,000 species, tropical Africa has 15,500, and the Indian subcontinent 26,000. Each of these regions supports large numbers of endemic species. A good example of the extent of endemism in the flora is provided by the Philippine archipelago where, out of a total of 7,620 species, 5,532 are only found here.

5.4 Phytomelioration for protection of soil from water and wind erosion

Soil erosion is an extremely serious problem all over the world. This is because of the vital role that soil plays in the life of the biosphere, and the fact that in many countries, as a result of strong human influence, the soil cover is in a critical condition. Soil cover is subject to massive degradation. The UN Conference on Environment and Development (Rio de Janeiro, 1992) stressed the paramount importance of combating soil erosion.

Soil erosion represents loss or destruction of soil, and consequent loss of fertility. It is primarily caused by either water or wind erosion. Water erosion occurs when soil is moved by surface flow of rainwater, melt-water, or irrigation water (see Irrigation). Wind erosion occurs under the influence of wind with a speed sufficient to lift soil particles from the surface.

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Chapter 6
Irrigation Strategies in Arid Zone Conditions

6.1 The demand for irrigation

Irrigation is an essential factor in the intensification of agricultural production under conditions of dry climate. It involves the use of complex science and technology. As a scientific activity, irrigation needs to be inter-disciplinary, involving the following subjects: mathematics, physics, soil science, hydrology, hydrogeology, hydraulics, economics, hydro-techniques and others. Irrigation is the guarantee of food safety for billions of people.

The level of civilization and quality of life inhuman societies are heavily influenced by the quantity and accessibility of the food resources available to them. Lack of food was a major hindrance to the development and evolution of our species. Civilization began when food reserves were sufficient to free human resources for the scientific-technical activity of increasing the production of high-quality food.

The process of humankind's settlement of the Earth has inevitably pushed separate groups of people to live under extreme conditions that were not amenable to extensive use of natural food resources. Agriculture became an obligatory element in the culture of the majority of contemporary nations. Different systems of agriculture came into being, with higher levels of scientific-technical sophistication in the more powerful economies.

The most fertile chernozem soils have arisen through the ecological interaction of mineral and biotic components in the Forest-Steppe and Steppe zones in regions of the planet with unreliable and insufficient natural moisture. Rice – one of the main food products for the major part of the Earth's population – is effectively grown only under conditions of prolonged flooding of the root system. Water in both these instances is the main limiting factor for the normal vital functions of plants used as agricultural crops, and watering is an obligatory requirement in such agriculture.

Within the regions of the planet with sufficient or excessive natural moisture the annual pattern of water requirement by crops is often at variance with the precipitation regime, resulting in significant reductions in yield. Watering of crops during the period of shortfall can prevent such reduction. Irrigation can be considered as a method of adaptation of people to severe natural conditions. By making the microclimate of irrigated territories more favourable for plant growth, time that would otherwise be devoted to tending the crops can be devoted to other more valuable activity.

At first glance it would seem paradoxical that a vast expanse of land surrounded by oceans should suffer from shortage of freshwater. The fact is that their major source of moisture is the water which has evaporated from the surface of the oceans. This water condenses and falls as rain, some of it onto the land. Some of this water evaporates again, some is carried away to the oceans, and some percolates into the ground to accumulate in soil and groundwater.

Over the planet as a whole and over every part of the continents, the process of water-exchange is constantly proceeding, sustained by solar energy. The nature of water-exchange is as follows: it is formed from the separate relatively stable and powerful streams of moisture coinciding with the principal atmospheric flows. Very large territories are largely missed by these flows of moisture, or they are situated along their periphery, and consequently they receive very little precipitation.

The paths of the major moisture flows are changing constantly and, as a result, even regions of the Earth with high annual rainfall can be characterized by extremely uneven seasonal patterns. Besides the normal long-term fluctuations of annual and seasonal rainfall patterns, other changes now being observed suggest large-scale alteration of the character of global water transfer.

Surface evaporation is one of the major elements of water-exchange and is formed under the influence of two principal factors, namely: the amount of water available, and the temperature. Evaporability, equating to surface evaporation, can be measured with special devices, and from this it is possible to calculate the maximum permissible evaporation, given unlimited water resources. Evaporation is related directly to the solar combined radiation, therefore latitude and seasonable variability is common to it, but each specific territory will have a relatively constant index.

The relationship between total evaporability and observed annual rates over a long period is called an aridity index, characterizing the climate of a given territory. Precipitation also creates river water flow. The volume of river flow depends on a large number of natural factors, the main ones of which are as follows: the relationship between intensity of rainfall and evaporation over the seasons (current aridity index); territory relief, particularly the thickness and depth of its erosion and cracking, and surface slope. The coefficient of river run-off, as ratio of run-off to total precipitation, increases with decline of dryness index and increase in average slope of river water- catchment. Relief by itself, as an influence on runoff, provides an explanation for waterlogging and soil salinization in catchments without run-off under conditions of low precipitation, as well as hydration of soils on steep slopes during heavy rain.

Water run-off partially proceeds by way of outcropping to the surface of an opened water-course. Ecological and hydro-geological conditions are of great importance in this process. Rocks and their sediments when adsorbing and containing precipitation can create steadier run-off through the year (i.e. flow with less amplitudinal variation).

6.2 Determination of irrigation needs

The water exchange on a specified area of land is an obligatory term for the determination of irrigation needs. Water balance is a qualitative index for water-exchange, represented as a qualitative relationship between water-intake and expenditure on a certain territory and over a definite period of time. Water balance within a river catchment over the hydrological year is recognized as the most commonly used parameter, and it may be represented by equation (1):

$$X = E + Y + \Delta V \qquad (1)$$

where X is precipitation; E evapotranspiration (is sum of land evaporation and transpiration); Y is surface and underground run-off; and ΔV is the change in water storage within a reservoir, being equal to the difference between its storage at the end and at the beginning of a year or vegetation period. The left-side elements of water-balance equation are called returnable and right-side elements are called expendable.

Evapotranspiration is composed of physical water evaporation from the land surface and water bodies, and from plants. The amount of e evapotranspiration depends on the temperature of the evaporating surface, moisture scarcity in a layer two meters thick over the land, moisture storage in the root layer, and the type and physiological state of the natural and cultivated vegetation. Under the most favorable conditions it may reach a definite maximum – E_0. River run-off does not directly act upon the vital functions of the plants. Water-storage in the root layer of the water-catchment (ΔW) is a more important factor for them.

Taking account of the above and equation (1), irrigation is required when the coefficient of natural territory moistening calculated by the equation (by analogy with dryness index) (2) is more than unity.

To determine which lands require irrigation it is enough to perform the division of the territory on districts by the p coefficient. To estimate the quantity of water for irrigation we have to select the crops, determine their sowing areas and multiply these areas by the gross water-need. Other natural and economic conditions may prove to be limiting factors. It is necessary to take into account and integrate many often contradictory conditions in the interest of efficiency and ecological safety in irrigation.

6.3 Soils

Soils are an important factor limiting irrigation. The most fertile black-soil and chestnut soils in areas of water scarcity and being used as a base for irrigated agriculture were formed over very long periods with constant growth of steppe grass, occasional heavy showers, episodically heavy rains, and sharp changes of air and land surface temperature.

Irrigation radically changes the soil-creation process. Under alternative agricultural monocultures, changing almost annually, nutrients are irrevocably removed and humus development ceases. Often irrigation with water, sometimes of unsatisfactory quality, promotes salinization of soils, giving rise to leaching and washing out of humus. Even watering by weakly-mineralized water can lead to the washing out of salts, particularly calcium, from the soil profile, resulting in leaching of the soil.

Soil cover is subjected to the indirect influence of irrigation through the other natural factors. Relief (geomorphology) of land surface determines the intensity of water-soil erosion processes. Geological structure and hydro-geological conditions determine the natural drainability of the territory and the predominant depth of the groundwater level, exerting a strong influence over the water-salt regime of soil-creation. Water erosion is an inevitable factor in soil-creation.

The destruction of rocks and minerals down to the size of soil particles, as well as transportation and distribution of organic substances, are both caused by water erosion. As a rule, under natural conditions a rather prolonged equilibrium is established between hydraulic deposition of soil and wash-out of soil, supported by the binding properties of plant root systems. Water flows above a threshold intensity destroy and wash out soils and even underlying material, so that gullies and ravines are formed. With irrigation, such phenomena occur more frequently due to the increase in water flow intensity and the poor soil-holding capacity of the crop root system.

There are two major types of water erosion: linear and plane. Both types occur under irrigation conditions. Erosion processes are inevitable where the irrigated land surface has a slope of more than 4 meters per mile, thus restricting the land which can safely be irrigated.

The geology and hydro-geology of the irrigated area determine the capacity and water-physical properties of the aeration zone. This is the zone lying between the surface and the top of the groundwater. The soil layer is located in the uppermost part of the aeration zone. With rare exceptions, the deeper the aeration zone, the better the conditions for irrigation.

The ground and soil in the aeration zone must have sufficient waterproof ability, characterized by least field moisture capacity. The higher the field moisture capacity the more water can be held in the aeration zone without draining into adjacent regions (horizons) under gravity. On the other hand a high field moisture capacity permits capillary rise from the groundwater. This favourable for irrigation under conditions of low mineralization and favourable chemical composition of groundwater, otherwise salinization occurs, unfortunately more often than most people realize.

The depth of the groundwater level is determined by interaction of field moisture capacity and surface water infiltration. If infiltration of surface water exceeds total losses, the level of the groundwater will rise. Conversely the level will fall if infiltration is less than the outputs. When groundwater rises into the aeration zone with ongoing evaporation, conditions are created for soil salinization. To avoid salinization, 70% of the flow of groundwater needs to be downwards, with a net downward flow in the aeration zone.

One of the necessary conditions for successful irrigation is that the land must be adequately drained. Such conditions are relatively rare in nature, and they are in conflict with the geomorphologic requirement that the land has to be nearly flat. Minimal slopes are typically poorly drained lands. One solution to this problem is to install artificial drainage but this results in an increase costs of investments.

Of a large number of factors affecting the feasibility of irrigation, one of the key determining points is the percolating capacity of the soils. The rate of percolation has to be close to the intensity of watering, otherwise surface water run-off erosion of soils may become a problem. On the other hand, percolation determines drainage load and high rates of irrigation become more expensive. Soil, geomorphological, and hydrogeological conditions are spatially very variable, and often one or more of these will completely exclude the possibility of irrigation. Many problems could be solved by not installing irrigation systems over very large areas, but instead using appropriate irrigation works on small areas where the conditions are particularly favourable.

Irrigation is only viable for highly intensive agriculture. It requires complex technical constructions: reservoirs with dams, canals, water-outlets and catchments, pumping stations, machines and devices for irrigation, and a drainage system. Only technically and economically developed countries can afford such facilities. Irrigation is a great art requiring huge knowledge, experience and skill, and often intuition.

6.4 Irrigated land

The greatest rise of irrigation in the world took place in the 1970s. But limited resources of land and water soon became exhausted, and large-scale reclamation construction requiring financial backing from the public sector nearly came to a halt in the 1980s. This continued only in the former Soviet Union country and a number of developing countries. At present we have no appropriate conditions for new large-scale irrigated agriculture projects, as further ploughing of permanent grassland or other vegetation would lead to sharp deterioration of the ecological situation. Moreover a significant area of irrigated land is taken out of agriculture annually from the territory of the former Soviet Union because of salinization and alkalinisation of the soils, deterioration of water quality in the irrigation sources, and the lack of resources for restoration of hydro-technical constructions. The state support system for irrigation has nearly ceased.

A special FAO Program on food support facilitates further development of irrigation, with the emphasis on efficiency, primarily with regard to reduction of water use per yield unit. The transition of bogharic lands into irrigated farmland should be carried out only after careful ecological evaluation.

Financial support for increasing technical sophistication of irrigation is limited by the state of the economy and the policy of the state, as well as the potential profitability of production based on irrigated agriculture. In general the limit of reasonable irrigation in developed countries has been reached, which is why the primary task for the next few decades must be the modernization of existing irrigation systems and watering equipment up to the world standard: the efficiency of water use in irrigation should be not less than 85%, and every thousand cubic meters of irrigation water should give no less than 40 food units per hectare.

Irrigation offers huge potential for increasing efficiency not only in crop production but in ecosystems in general. It allows the transformation of desert, semi-desert and steppe landscapes into forest-steppe and habitats generally favourable for human life. This is why ecosystems are currently considered as the main targets for irrigation management. The hierarchy of management levels has undergone some important changes. Cultural and natural biocenoses have been put in the forefront. The main task is provision of the physical medium – a biotope beneficial for the development of efficient biocenosis. Creation of favourable conditions for people is also an important factor.

Nowadays more than 250 million hectares or 17% of total cultivated land is under irrigation. Asia occupies first place (175.4 mln ha), followed by North America (30.1), Europe (22.5), Africa (12.3), and South America (9.8). Irrigated land yields more than 40% of world food production. Vegetables, food cultures and some grain cultures are grown in many countries under irrigation conditions yielding substantial addition to crop yields.

Land and water resources are the chief factors limiting irrigation. Further development of irrigation will be aimed at reduction of expenditure on water and energy, with simultaneous increase in ecological safety of irrigation agriculture, particularly where this involves ploughing of old grassland or reclamation of other habitats.

6.5 Regimes of irrigation

In arid climates all plants, including agricultural crops, experience a water deficit equivalent to the difference of maximum possible gross evaporation and the quantity of fallen precipitation. The deficiency of water-consumption by irrigated crops forms the basis for the irrigation regime, namely: fixing of the terms and watering rates.

Water-need is a modern synonym for irrigation rate. It is necessary to distinguish the current net-water-need M_n, equal to the difference between precipitation and biologically optimal gross-water-consumption of the specific agricultural crop under specific climatic conditions, and the current gross-water-need M_b, which includes the inevitable losses of irrigation water for filtration and run-off during irrigation. The rate for net (gross)-water-need is taken as an average over many years, and is the basis for the definition of irrigation water-need.

The water-need depends on the type of irrigated crops and the climatic conditions in each region, and to characterize the need of each crop in each region, we can use the coefficient α. Table1 shows that rice crops have the highest rate of net-water-need, because of insignificant evaporation from the water surface. Of the so-called field crops, cotton comes first, followed by perennial grasses, vegetables, and corn.

Long-term fluctuations in net-water-need, taking account of weather conditions, are obtained by ranking observed and calculated rows in ascending order with definition of the mathematical probability of exceeding the provision of water for every member of the row. Under this approach the drier the climatic

Table 6.1. difference between the rate of net-water-need on average, by water-provision year and in a dry year. (Kovalenko et al., 2002).

Natural climatic zone	Beneficial water use, thousand m^3/ hectare									
	Cotton	Wheat			Maize			Vegetables		Rice
	95%	50%	75%	95%	50%	75%	95%	50%	75%	95%	95%
Desert	12.5	-	-	7.4	-	-	6.3	-	-	16.8	24.0
Semi-desert	9.5	-2.6	2.7	3.3	4.3	4.8	5.3	4.9	5.9	6.2	16.0
Stepp	-	1.9	2.5	3.2	2.6	3.2	3.9	3.9	4.1	5.1	10.0
Foest-Steppe	-	1.4	2.0	2.7	1.3	1.9	2.5	2.1	2.8	3.7	-

conditions, the greater the net-water-need and hence greater provision of water, and a lower probability of exceeding the water-need in the wetter years. Table 6.1 presents the difference between the rate of net-water-need on average, by water-provision year and in a dry year.

Inevitable losses of water during irrigation are estimated when determining the net-water-need rates. Figure 6.1 shows the classification of the losses and their possible amounts. Coefficient α characterizes losses of water during irrigation in relation to the total volume of water fed for these purposes. The amount and the nature of losses are different for separate technological irrigation cycles. The more complicated the irrigation technology, the bigger α_0 .

Figure 6.1. The tree of water losses in irrigation (Kovalenko et al., 2002).

As a rule the following are present in irrigation technology:

- distribution of water between irrigation systems with the help of main canals (α_1) ;
- distribution of water between farms (users) (α_2) ;
- intra-farm distribution of water between fields and watering techniques, canals and pipelines (α_3),
- finally the watering of agricultural crops (α_4).

If the coefficient of losses in each of the above-mentioned stages is designated as α_1, α_2, α_3 and α_4, we have:

$$\alpha_0 = \alpha_1\alpha_2\alpha_3\alpha_4 \qquad (3)$$

$$M_b = M_n/1 - \alpha_0 \qquad (4)$$

Each irrigation regime depends on the specific local climatic conditions of the watering season and is a rather changeable value.

Sources chapter 6

Sections 6.1-6.5 adapted from: P.I. Kovalenko, Yu.A. Mikhaylov and O.I. Zhovtonog, 2002 *Irrigation* in "Agricultural land improvement, amelioration and reclamation Vol I.", UNESCO Publishers, Oxford, UK. p. 36.

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Chapter 7
Irrigation Systems – Machinery and Technologies

7.1 Introduction

This chapter presents irrigation systems, their classifications by design features and types of water supply, range, and geomorphologic location, with characteristics of irrigation system components. System computation methods are given. Different designs of the irrigation system are considered: open, piped, and combined, as well as design methods. Design features of different irrigation methods for agricultural crops (surface, drop, subsoil, sprinkler, and mist irrigation) are presented, as well as rice systems and systems using wastewater and liquid manure. The questions of computer-based management and operation of irrigation systems are also considered.

Irrigation is the supply of water to fields that lack moisture: it provides an optimal water regime within a root zone for the development of agricultural crops, and is one of the main methods of reclamation. It consists of a complex of engineering, agronomic, and organizational-economic activities based on hydraulic engineering techniques of rationed water supply to soil to provide soil moisture.

Irrigation is required when there is a lack of natural moisture for crops, either for the whole vegetation period or at different stages of development. Without it the highly productive use of agricultural land is impossible. Because of irrigation, favourable moisture and other related soil regimes are established. These are necessary for enhancing fertility, obtaining a high and steady harvest, and the essential improvement of farming production quality. Irrigation makes it possible drastically to improve the soil conditions of dry zones and make them suitable for agricultural use, and to make more productive use of those regions that are adequately wetted. In the latter case irrigation is an indispensable prerequisite of the development of cotton and rice growing, grain production (with the creation of guaranteed grain harvesting zones), fodder crop and vegetable growing, horticulture and livestock breeding (the secondary sowing of fodder crops on irrigated land, and the creation of pastures and hay land).

7.2. Irrigation systems

An irrigation system consists of the hydraulic structures (water intake and pumping stations, canals and pipelines, and so on) and operational structures (roads, highways, bridges, and so on) within an area of land that provide irrigation to the area. There are systems for regular irrigation, basin irrigation, and irrigation impounding (impounding irrigation). The regular irrigation system consists of:

- a water source;
- a head water intake (that withdraws water from the water source and protects the irrigation system from silting, debris, and garbage);
- the irrigation network;
- a disposal network;
- a collector-drainage network (for drawdown of the groundwater table and disposal beyond the irrigated area);
- hydraulic structures;
- pumping stations;
- irrigation equipment;
- operational structures (roads, bridges, and so on); and instruments for monitoring reclamation and the state of the irrigated lands, communication lines, forest belts, and so on.

Irrigation systems can obtain their water supply from canals by gravity or mechanical lift (where water is supplied by a pumping station). The irrigation system efficiency is expressed as the ratio of water discharge supplied to the field (Q_{net}), to the volume withdrawn from the water source (Q_{gross}).

The rational use of water resources requires an irrigation system efficiency of 0.8 to 0.9 for the inter-farm distributing canals; 0.85 to 0.95 for farm ditches; 0.9 to 0.95 for annual ditches (that is, ditches redug each year); and 0.95 to 0.98 for buried networks.

With the aim of improving the irrigation system's efficiency and reducing seepage loss, use is made of lining materials and revetment (concreting and asphalt paving of bottom slopes, screens of polyethylene film, polymer-concrete and clay), sealing, solonetzification, and gleyzation of the canal bed. The irrigation system efficiency is much higher when buried pipelines are used.

There are three types of irrigation system design:

- Open (commonly practiced) with earth ditches (lined or unlined) or flumes erected on supports of different height, buried irrigation systems (most advanced), where ditches are replaced with pipelines, and combined irrigation systems: these are combinations of open ditches and pipelines.

- The large combined irrigation systems have open canals as main supply canals, whereas distributing and water application networks use buried pipelines;
- Small irrigation systems have buried pipelines for the distribution network, while the water application network has annual ditches or connecting furrows. Water is supplied to pipelines by mechanical lift, pumping, or by gravity (owing to the natural slope).

The choice of the irrigation system design is made on the basis of comparison of the engineering and economic alternatives for the particular irrigation area. Irrigation systems are classified as described in Table 7.1.

7.3 Water intake

Water intake structures: are hydraulic structures for water withdrawal from rivers and subsurface sources to irrigation systems. The intake structures are located in the head part of the system, and therefore they are often named head works. In order to withdraw water from rivers, use is made of intake structures with dams and without dams. A water intake without a dam is an artificial bed (canal) that branches at an angle and takes a part of river water discharge. Intake structures without dams are built when river levels and discharges make it possible to withdraw by gravity into the main canal.

The simplest type of intake structure without a dam is an open ditch dug from the river to the irrigation system, without a permanent structure at its head. With big river discharges, use is made of intake structures with dams that constitute part of the hydraulic structure. They are built with over falls. Usually, the over fall height is determined according to the difference in elevation of the main canal entrance and the riverbed average.

The water intake structures are arranged at the side of the dam or in the riverbed within the dam site. When water is to be supplied to higher elevations and for pump irrigation, there is a need for pumping stations. Groundwater withdrawal is achieved with the help of tapping, open wells, and drilled wells.

An irrigation network: consists of permanent and temporary canals, and pipelines that supply water from the irrigation water source to the irrigated area. The irrigation network, both permanent and temporary, consists of conveying and regulating networks with water meters, and is provided with apparatus to enable the raising of water level in canals, to regulate discharges (head regulators, sluice offtake regulators, escape-regulators, outlets), for inlet-outlet canal transitions (falls, drop structures), sediment detention (desilting basins, guiding systems), and so on.

Table 7.1. Classification of irrigation systems (Huber, 2002).

Classification attribute	Types of irrigation system	Design features
Irrigation system design	Open (surface)	All components of irrigation network are open ditches or flumes
	Buried (subsurface)	All components of irrigation network are pressure or non-pressurized pipelines
	Combined	Combination of open ditches and buried pipelines
Type of water supply	Gravity	Water comes from the irrigation source by gravity
	Mechanical lift	Irrigation source is located below irrigated area and water is supplied by pumping station (pump irrigation)
	Gravity-pressure	Water is conveyed via buried pipelines by gravity down a natural slope
Extent of steadiness	Solid-set	Intake structures, pumping stations, irrigation network and water application facilities have a permanent location
	Semi-stationary	Intake structures, pumping stations and irrigation network have a permanent location while water application facilities move from one position to another
	Traveling	All components of the system—pumping stations, irrigation network (mountable) and water application facilities travel from one position to another
	Stationary-seasonal	A kind of stationary system in which all components are assembled in the field early growing period, and are removed after harvesting
Geomorphologic location	Foothills	Intake structure without dam. Main canals are located along or at a sharp angle to natural slope
	Valley	Intake structure without dam or with mechanical lift. Main canal grade is less than that of the river.
	Watershed plains and plateau	Intake structure with mechanical lift. Main canal runs through watershed with dual command.

The conveying network of an open irrigation system consists of the main canal, inter-farm, farm, and in-farm distributing canals (ditches). The conveying network canals are operated during the growing season, permanently or during long cycles. The main canal supplies water from the water source into the inter-farm distributing ditches, which convey it to the farms, while in-farm distributing ditches supply water to the fields or irrigated area. In some cases the conveying network does not have a complete set of canals.

For the effective operation of canals and structures, the water volume needed at any point in time should be conveyed with the maximum efficiency of canal and land use and the minimum of construction and operation expenses. The indispensable conditions of an irrigation network functioning through gravity are that the main canal should command a water level difference of 10-22 cm over the irrigated area, and that senior-order canals should also have a water level difference over inferior-order canals.

The conveying network of buried irrigation systems consists of the main pipeline that supplies water from the irrigation source to the distributing pipelines.

The regulating network of open irrigation systems consists of ditches (dug annually) and connecting furrows from which water is supplied to the water application network (furrows or strips) or is taken by sprinklers and other irrigation facilities. The open regulating network is dug annually before irrigation begins and is leveled after the season, or before every water application and during each after-irrigation cultivation.

7.4 Irrigation network

An inter-farm irrigation network serves to deliver (transport) water to the irrigated fields and to distribute it among the various irrigated areas and water users on the farms. The inter-farm network consists of main canals and pipelines, various hydraulic structures (command and water distribution units, field delivery points, proportional dividers, etc.).

An in-farm irrigation network is a system of waterways – canals, buried and open water conduits, etc – that serve the fields of a farm. An inter-farm escape network: in an irrigation system consists of water-receiving escape and collector networks, and serves for the diversion of excess water from contour canals. It also comprises earth flow storage, and rain storm discharge channels with structures for catchment and diversion of the surface runoff (rainstorm or melt water) from the overlying sites as well as saline soil and flushing waters.

An in-farm diversion network in an irrigation system is subdivided into "collector escape" and "collector drainage" networks, and serves to divert from the farm's irrigated area any wastewater and excess surface water resulting from irrigation, rainstorms, emergency accidents, flushings, emptying of canals (flumes, pipelines), and groundwater that lies too close to the surface.

An irrigation canal supplies water to the irrigated land areas. There are main canals, inter-farm canals, in-farm ditches, and field ditches. Water is supplied to the irrigation canal either by gravity or by pumps. Canals may be in the form of earth ditches or may have a seepage-proof revetment (concrete, reinforced concrete, bituminous concrete, or polyethylene film). The cross-section of big canals is parabolic or rectangular, while that of small canals is trapezoidal.

Ameliorative canals are artificial channels of regular form with unconfined water movement, dug in earth (as pit, embankment, or cut-and-fill) and designed for land reclamation. Usually, a system of main distributing irrigation canals (ditches) and escape canals is built. Canals other than escape canals are as a rule traced along the highest elevations. In large irrigation systems the main canals can be several hundred kilometres long, and their discharge in the head part can be as much as 250-500 m^3/sec. The ditch length ranges between 100 and 2,000 m, and discharge is at 30-150 litre/sec.

The shape of cross-section is dependent upon the canal designation, the construction properties of the soil, and earthwork conditions. The dimensions of cross-sections are determined by hydraulic calculations for the given water discharge and permissible velocities. The type of soil and canal dimensions dictates the slopes. The permissible flow velocities should range between maximum values that exclude possibilities of bed scouring and minimum ones that prevent silting and overgrowth. Lining of the bed (revetment) of the canal serves to prevent scours, reduce seepage losses and channel and slope roughness, and improve the carrying capacity. Among the different methods are colmatage (mudding), mechanical consolidation of the soil, and films of synthetic materials.

The main canal in an irrigation system is the basic conveying channel that supplies the irrigated area with water. It consists of two parts: one conveys water from the water source to the first distributing canal, and the second (working) part branches water into distributing canals. The irrigation lateral takes water from the main canal to provide individual parts of the irrigation system, which are arranged according to farm layout, type of topography, or other attributes.

A water conduit is a structure (canal, flume, tunnel, pipeline, etc.) that serves for the conveyance, distribution, and diversion of water.

Flumes in the irrigation network are open irrigation canals made of prefabricated reinforced concrete parts of semi-spherical or parabolic shape installed on the surface, upon supports, or in trenches. They belong to the conduit network of the irrigation system. Owing to the flumes there are no seepage losses. Flume length varies from 6 to 8 m. Water is taken from flumes by siphons or outlet conduits.

An annual irrigation network is the first link of the water distribution network over the irrigated field and consists of annual ditches, and distributing and irrigation furrows and strips restored every year.

7.5 Inundation and salinity of irrigated land

Theoretical and practical questions concerning drainage of irrigated land are considered. The main causes of inundation and secondary salinization are discussed, and calculations are presented for rise of groundwater level and accumulation of toxic salts on irrigated land. Information on soil salinity types and their effect on growth and development of crops are summarized. Calculations are presented for assessment of the need for drainage on irrigated land, for both horizontal and vertical drainage, and their parameters. The final section provides information on biological drainage, including its construction and disposition schemes, as well as its efficiency.

Land irrigation as mean of agricultural intensification was important as long ago as the third and fourth centuries B.C. At that time, there were complex and effective irrigation systems in many countries (e.g. Mesopotamia, Egypt, India, etc.). At the same time, history knows many cases where large areas of irrigated land became worthless as a result of radical change of hydrological and geochemical conditions, and land salinity. Prevention and struggle against these phenomena, in spite of centuries-old experience, was only achieved in our time. According to the Wyoming Experimental Station and the US Bureau of Drainage Research, even in the earliest days of drainage development in the western states of USA, there were serious complications connected with land inundation and salinity.

Also, the emphasis was put on raising the level of groundwater, even where it was relatively deep (≥10-20 m). This report relates to 1908-1909 but in 1944, according to the Department of Agriculture, as a result of inundation and salinization more than 100,000 ha of irrigated land was removed from agriculture. Disastrous over-inundation and salinization of irrigated land has occurred in other countries of Europe, Asia and Africa. Inundation of irrigated lands is linked with rise of groundwater level, following soil over-moisturing and intensive evaporation. The value of the level may be determined by means of critical bedding depth (Δ_{cr})

$\Delta_{cr} = 170 + 8t +/- 15$ (cm)

The evaporation from groundwater surface with (E_r) depending on bedding depth Δ_{cr} (2) where t is average annual air temperature, in ^oC; E_o is evaporation from water surface, in mm.

Δ is bedding depth of ground waters, cm; n is in the exponent, n=1-2. The main reasons for rise in groundwater level and inundation of irrigated land are filtration water losses from irrigation channels and water losses during watering (in a leaching regime).

The probability and timing of groundwater level rising to critical values and causing land inundation may be determined by means of long-time prognosis of groundwater dynamics, depending on hydrogeological conditions, methods and technology of land irrigation. The methods of groundwater dynamics calculation were based on solution of equations of unsteady water motion in grounds with different degrees of saturation.

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As a rule, prognoses are made for 5, 10 or 15 years. Simultaneously with prognosis of groundwater level change, prognosis can be made for mineralization and chemical composition change.

7.6 Reasons for secondary irrigated land salinity

Land salinity may be primary (natural) or secondary (technogenic). Naturally saline soils are those whose solid and liquid phases contain readily soluble salts in a concentration high enough to decrease soil fertility and negatively affect the growth and development of crops. Secondary saline soils are those where readily soluble salts have accumulated during irrigation. Without analysing the existing water and salt regimes in the soil and forecasting possible changes in these regimes during irrigation, it is impossible to identify in advance land prone to secondary salinization. In general terms, lands liable to secondary salinization during irrigation are t hose where the soil, subsoil and groundwater contains readily soluble salts which may create toxic conditions for the crop during irrigation.

Methods for calculation of salt regime dynamics during irrigation are based on joint solution of equations of salt and water motion in soils, subsoil and groundwater, taking into account convective diffusion, salt dissolution in solid phase, and phenomena of ion exchange sorption. Theory and practice of irrigation in different countries of the world show that secondary soil salinity depends on natural and economic factors including groundwater level and mineralization, value of watering norms, the technical condition of irrigation systems, methods and technology of crop watering, mineralization and chemical composition of irrigation water, and physical and chemical properties of soils.

Saline soils are found mainly in arid regions. The general area of saline soils, as percentage of the arid land, is as follows: in Europe and Asia 20%, Africa 6%, North America 3%, South America 35%, and Australia 57%. Among saline soils there are those containing salts in the upper layer (0-100 cm); badly saline areas where salts are present in in the 100-200 cm layer, and potentially saline areas where salts may be found in underlying strata (within the aerated zone) or in groundwater. Besides the depth of the salt horizon, saline soils can be categorized by salinity degree, salt composition and their distribution in the salt profile. Salt composition may be estimated by ion correlation, salinity degree (as total or toxic salts), or content of particular ions. For categorizing soils by salinity degree, data from water extraction analysis

Sources of chapter 7

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Chapter 8
Amelioration of Alkali (Soda-Saline) Soils

8.1 Diagnostics and main properties limiting the fertility of soda-saline soils

Data on the diagnostics and quality assessment of alkali (soda-saline) soils are outlined. The properties limiting the fertility of these soils and the means of their amelioration are considered. The methods of calculating the optimum requirements of chemical amendments and leaching required to remove toxic salts (including those that appear in the soils after their treatment with an amendment) are described. The peculiarities of amelioration of soda-saline soils in conditions of irrigation and dry farming are discussed. Examples of successful management of reclaimed soda-saline soils are given

Soda-saline soils represent a subgroup of alkali soils distinguished by the presence of sodium carbonates (Na_2CO_3 and $NaHCO_3$) in the soil solution in amounts that hamper the development of crops and exert a negative effect on the soil quality. Some other soluble salts (chlorides and sulphates of sodium and magnesium) may also be present, but the dominant role in forming adverse soil properties and conditions for plan development is played by sodium carbonate. Unlike the subgroup of sodic (solonetzic) alkali soils, soda-saline soils, especially those with a high content of salts, do not have a morphologically distinct solonetzic (natric) horizon.

According to I. Szabolcs, soda-saline soils can be categorized as a subgroup of alkali soils without a natric horizon (subsurface clay- illuvial horizon with columnar or columnar-prismatic structure and having ESP > 15). Thus, the presence or absence of a morphologically distinct natric horizon serves as the basis for the division of alkali soils into two subgroups that require different amelioration measures.

The main factors limiting the fertility of sodic (solonetzic) soils are their poor water-physical and agrophysical properties. The fertility of soda-saline soils is limited by their chemical and physico-chemical properties, which are affected by the presence of sodium carbonate in the soil solution. These soils are strongly alkaline (pH 9-11), which entails the absence of calcium in the soil solution. Hence, the exchange complex of soils is saturated with exchangeable sodium.

The exchangeable sodium percentage (ESP) in soda-saline soils reaches 40-80% of the cation exchange capacity (CEC). The prevalence of exchangeable sodium in the exchange complex causes clay peptization, degradation of soil aggregates, a decrease in the water conductivity, very high bulk density of soils (compactness) when dry, and their oversaturation with water when wet. Thus, in addition to strong alkalinity, soda-saline soils are characterized by the adverse water-physical properties typical of sodic (solonetzic) soils. If the topsoil horizon of soda-saline soils contains more than 0.5-0.7% of Na_2CO_3 and $NaHCO_3$, determined in a 1:5 soil-water extract, and has an electrical conductivity (EC_e) value of higher than 8-16 dS/m, then this soil can be distinguished as a soda-affected solonchak – solonetz, characterized by the presence of morphologically distinct solonetzic (natric) horizon on the background of soda salinization.

The high alkalinity of soda-saline soils adversely affects most of crops and soil biota. Alkaline conditions lead to the disturbance of metabolic processes in plants and disrupt the nutrient balance. In particular, the availability of calcium, magnesium, phosphorus, iron, manganese, and several other essential nutrients considerably decreases. Soda (sodium carbonate) is considered the most toxic of all the soluble salts found in natural soils. According to *Soil Taxonomy* and many national classifications, soda-saline soils are diagnosed on the basis of a combination of two analytical indices: the EC_e and the ESP. If the soil has an EC_e greater than 4 dS/m and ESP above 15%, it can be referred to as an alkali soda-saline soil. Along with EC_e and ESP, the sodium adsorption ratio (SAR) is often used for diagnostic purposes. The SAR value allows one to estimate the probability of the appearance of exchangeable sodium in the exchange complex, and, hence, to predict the development of solonetzic processes in the soil. The SAR value is correlated with ESP.

The *residual sodium carbonate* (RSC) content is also used to characterize soda-saline soils. The RSC value is calculated by subtracting the sum of exchangeable calcium and magnesium from the total alkalinity (the concentration of HCO_3^- ions in the water extract) of the soil, expressed in cmol/kg. In Russia and several other countries, the study of water extracts (with a soil to-water ratio of 1:5) is used to characterize the degree of soil salinity. Soda-saline soils are distinguished in the classification of salt-affected soils accepted in these countries according to the following criteria:

$HCO_3^- > 0.8 – 1.0$ cmol/kg
pH (1:2.5) > 8.5
$HCO_3^- > Ca^{2+} + Mg^{2+}$

The sum of toxic soluble salts in the root zone is also taken into account to classify soda-saline soils (as well as other salt-affected soils) by their degree of salinity (Table 8.1)

Table 8.1. Assessment of soil salinity by the sum of toxic salts and the content of separate Ions (Pankova, 2002).

Degree of soil salinity	**Soil salinity index in relation to the composition of salts**							
	Predominantly chlorides			Predominantly sulfates (including the chloride–sulfate type of soil salinity)		Predominantly sodium carbonate/ hydrocarbonate		
	Stox**	Cl^-	Na^+	Stox**	Na^+	Stox**	HCO_3^-	Na^+
	%	cmol kg–1 soil		%	cmol kg–1 soil	%	cmol kg–1 soil	
Non saline	<0.05	<0.3	<0.6	<0.15	<1	<0.1	<0.8	<0.6
Slightly saline	0.05–0.12	0.3–1	0.6–2	0.15–0.30	1–2	0.1–0.15	0.8–1.4	0.6–2
Moderately saline	0.12–0.35	1–3	2–4	0.3–0.6	2–6	0.15–0.30	1.4–2.0	2–4
Strongly saline	0.35–0.70	3–7	4–8	0.60–1.0	6–12	0.30–0.60	2.0–3.0	4–8
Very strongly saline	>0,7	>7	>8	>1	>12	>0.60	>3.0	>8

* The degree of soil salinity can be estimated by any of the indices given in this table

** The sum of toxic salts (S_{tox}, %) is equal to the sum of toxic ions expressed as a percentage of the soil mass. Cl, Na, and Mg ions are considered toxic ions; HCO_3(tox) = $HCO_{3(total)}$ – Ca (mmol$_c$.kg^{-1} soil (2x)); $SO_{4(tox)}$ = $SO_{4(total)}$ – (Ca-HCO_3), meq 100 $^{g-1}$ soil. $S_{tox} = HCO_{3(tox)} + Cl + SO_{4(tox)}$ +Na+Mg+K,%.

8.2 Theoretical basis: the goals of amelioration of soda-saline soils

Along with purely soda-saline soils, soda-chloride and soda-sulphate saline soils are distinguished. Soda-saline soils, as well as other salt-affected soils, can be sub classified according to the depth of the saline horizon and the presence (or absence) of calcium carbonates in the soil profile. All these features are of great importance for the choice of proper soil amendments and amelioration methods.

The indices used in the Russian classification of salt-affected soils are also applied in several local (regional) classifications. For example, the group of saline soils includes not only solonchaks and the soils with strongly saline surface horizons (salic soils), but also alkali soda-saline soils that contain a horizon enriched with soluble salts at a depth varying from 0 to 125 cm. The depth of saline horizon is taken into account in establishing sub classification. Soda-saline soils can be also subdivided into three groups – hydromorphic, semi hydromorphic, and auto morphic (meso morphic) soils – with respect to the depth of the groundwater table. Hydromorphic soda-saline soils are most widespread; groundwater often serves as the source of sodium carbonate in these soils. The groundwater depth is a key parameter to be considered when selecting methods of soil amelioration and determining the sources of sodium carbonate in the soil.

V.A. Kovda revealed the relationship between the properties of soda-saline soils and their relative fertility. His assessment of soda-saline soils was based on three major indices: (a) the total alkalinity in water extracts (1:5) from the soils, (b) the ESP, and (c) pH. At HCO_3^- 0.02-0.04%, ESP 5%, and pH 7.5-8.5, the relative fertility of the soil is estimated as 100%; at HCO_3^- 0.05-0.06%, ESP 10-15%, and pH 8.5-9.0, it decreases to 60-75%; and at HCO_3^- 0.07-0.08%, ESP 10-15%, and pH 9.0-9.5, it is as low as 20-30%. When these values are higher, the soil becomes virtually infertile.

8.3 The Genesis of Soda and Geographic Distribution of Soda-Saline Soils

The origin of soda (Na_2CO_3) in the soils has been thoroughly studied (V.A. Kovda, N.I. Bazilevich, I. Szabolcs, etc.). It is found that soda can appear in the soils owing to different geochemical and soil processes:

The weathering of parent rocks containing sodium alumina silicates results in the synthesis of soda:

$$Na_2SiO_3 + H_2O \rightarrow 2NaOH + SiO_3 \quad (1)$$
$$2NaOH + H_2CO_3 \rightarrow Na_2CO_3 + 2H_2O \quad (2)$$

This process was thoroughly described by B.B. Polynov, using the example of salt affected soils in Mongolia. Afterwards, Kovda demonstrated the significance of this process in the origin of soda in different regions.

The interaction between calcium carbonate and chloride–sulphate–sodium salts (the Hilgard reaction, 1892):

$$CaCO_3 + Na_2SO_4 \leftrightarrow Na_2CO_3 + CaSO_4 \quad (3)$$
$$Na_2SO_4 + Ca(HCO_3)_2 = 2NaHCO_3 + CaSO_4 \quad (4)$$

The interaction between calcium ions in soil solution with exchangeable sodium (Gedroitz, Sigmond, Kelley).

The biochemical synthesis of soda as a result of the activity of sulphate-reducing microorganisms in anaerobic conditions and in the presence of organic matter and sodium sulphates:

$$Na_2SO_4 + 2C \rightarrow 2CO_2 + Na_2S \quad (5)$$
$$Na_2S + CO_2 + H_2O \rightarrow Na_2CO_3 + H_2S \quad (6)$$

This particular mechanism of soda formation was found by I.N. Antipov-Karataev on sodium-saline soils in the Russian plain, by A.R. Verner and N.V. Orlovskii in Western Siberia, and by I. Szabolcs in Hungary. The biochemical process of soda formation is typical in marshland soils, bottoms of shallow lakes, sea lagoons, and coastal deltas (Kovda). It is known that the synthesis of soda can also be due to denitrification of nitrogen-bound sodium compounds.

8.4 Soda formation is related to the mineralization of organic matter

Some salt-resistant crops can accumulate considerable amounts of alkaline carbonate salts, which get into the soil in the course of the biological turnover of substances. Kovda emphasized that alkaline carbonates can accumulate in the soil in a form of organic acids, which, interacting with carbonic acid, produce sodium (and potassium) carbonates. According to Kovda, a similar process takes place in deep zones of the Earth's crust, within the areas of oil fields. Usually, deep groundwater in such areas is rich in bicarbonates and carbonates of alkaline elements. In places of groundwater discharge, the soils are affected by soda salinization. Thus, head groundwater may serve as the source of soda in the soils.

A new theory of soda formation in the soils has recently been suggested. It argues that soda can appear upon the selective leaching of ions from surface horizons of salt affected soils. This phenomenon has been observed in experiments, but has not been proved for natural soils; it is rather a hypothesis than a theory. In general, in spite of a long history of investigation, the problem of the genesis of soda in soils is still an object of interest. It is evident that a range of soil and geochemical processes may be responsible for soda salinization of soils.

Soda-saline soils are widespread in many countries, but their exact extent is still unknown. In FAO-UNESCO data, the area of soda-saline soils is included in the total area of alkali soils. Numerous publications in which the soda-saline soils are described prove their widespread distribution in the United States, India, China, Russia, Armenia, and other countries.

The geography of soda-saline soils shows that they are most often found in particular natural zones: deserts, semi deserts, steppes, and forest-steppes. Local areas of these soils are also found in the boreal forest zone. The northernmost area of soda-saline soils is located in the taiga zone of Yakutia, where permafrost-affected soda-saline meadow soils have been described. These facts indicate that the conditions of formation of soda-saline soils are very diverse. These soils appear in different environments. The genesis of soda can be related to different processes. Therefore, it is impossible to recommend a uniform amelioration technology that can be efficiently applied to all soda-saline soils. At the same time, the main principles of amelioration measures applied in different regions have much in common, as can be seen from analysis of the literature on it.

8.5 Amelioration of soda-saline soils

The essence of interactions between soil solutions and the exchange complex was experimentally studied and theoretically substantiated in the beginning of the twentieth century (the works of K.K. Gedroitz, A.A. Sigmond, W.P. Kelley, and E.W. Hilgard). There were thorough investigations of the physicochemical properties of saline soils, cation-exchange and cation adsorption processes that govern the genesis and determine the amelioration measures of salt-affected soils. Later, important contributions to this subject were made by V.A. Kovda, I.N. Antipov-Karataev and E. Bresler with co-authors, as well as D.L. Suarez, and other scientists from different countries. However, the study of physicochemical processes in saline soil still remains relevant today. We need to know in detail the processes that take place in soil upon application of chemical amendments.

The goal of amelioration of soda-saline soils, including solonetzic and solonchakous varieties, is to improve their fertility through certain impacts on their physicochemical, agrophysical, and water-physical properties. This can be achieved by using chemical amendments, agro technical measures (special soil cultivation procedures), and phytomelioration, in combination with soil leaching to remove salts under natural or, sometimes, artificial drainage.

The aims of chemical amelioration of soda-saline soils are to neutralize soil alkalinity and to replace exchangeable sodium and magnesium in the soil exchange complex by calcium. Calcium adsorption by the exchange complex enhances the coagulation of soil colloids and improves the water-physical state of soils, which is necessary for the successful leaching of water-soluble salts from the root zone.

The application of various soil amendments is expensive when a moderate or strong degree of salinity is observed in the upper 100 cm depth of the soil. In conditions of a shallow groundwater table and poor natural drainage of the territory, artificial drainage systems are required. In order to improve the fertility of chemically reclaimed soils and to eliminate the residual solonetzic properties of the soils, organic fertilizers (manure, composts and green manure crops) should be applied and special soil-improving (meliorant) crops should be grown.

Sources of chapter 8

Sections 8.1-8.5 adapted from: Pankova Ye.I., Redly M. , Aidarov I.P. and Pestov L.F., 2002: *Amelioration of Alkali (Soda- Saline) Soils i*n "Agricultural land improvement, amelioration and reclamation Vol II.", UNESCO Publishers, Oxford, UK p 22.

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Chapter 9
Conservational Soil Treatment

9.1 Introduction

This chapter considers practical measures to protect soil from erosion and deflation. It has been noted that in regions where water occurs, great attention should be paid to the anti-erosion organization of the areas that form the framework of the following linear borders: forest belts on cropland, road networks, the borders of agricultural lands, crop rotations and fields, ridge-terraces with wide bases, and others on slopes.

Water-preserving forest belts should be located on straight, even slopes across their inclination, and along the contour lines on complex slopes. Forest belts perform a range of functions over long periods, and the ground leading to them should be solid, as roads and field tracks are generally associated with them. They serve as guidelines for the movement of agricultural machines when soil is being processed, crops are being sown and cared for, and anti-erosion practices are being applied on slopes.

In regions where there is deflation, wind-breaking forest belts are laid out across the main deflation-prone areas. Strip sowing, buffer strips of grasses, and other measures to protect soil from wind erosion are placed along them.

The basic methods of soil processing (tillage) and soil management practices applied in conservational soil treatment are described in detail. The article considers the effects of crevice cutting, socket making, mole-hilling, and also of mold boardless, chisel, surface, trash-cutting, and other kinds of tillage on wind and water erosion, on moisture retention, conservation, and crop yield. Technological schemes of meadow making on eroded lands and their impact on soil and environment protection are outlined.

The term "conservational soil treatment," along with the conventional definition of farming systems, can be applied in a wide sense to the protection of soil from all kinds of degradation in order to conserve its fertility, make efficient use of land resources, increase the yield of cultivated crops, and diminish negative ecological effects. The term is often used in a narrower sense for measures to protect soil against erosion and deflation processes. Erosion and deflation affect 84% of the total area of degraded soils.

The destructive effects of water running down sloping cropland have been apparent to farmers throughout history in the years after new parcels of land has been reclaimed by ploughing up natural vegetation or cutting down the forest and clearing the land. To prevent soil loss and scouring on the reclaimed slopes and to protect crops from perishing, farmers have sought the best protection they could in the light of the knowledge available to them.

9.2 How to combat erosion

Terracing, afforestation of mountain slopes, and soil processing across the slope are among the most ancient practices of protecting soil from destruction by erosion and deflation. Terracing steep mountain slopes to grow valuable fruit crops and forests on them was practiced in ancient China, by the Incas in the territory of present-day Peru, in Armenia, in many Mediterranean countries, and in a number of other regions. Terraces were built by hand, sometimes with sheer slopes made of masonry. This reduced soil loss considerably but could not completely protect the land from erosion, especially when there was heavy rainfall with a considerable precipitation layer. Terraces were frequently damaged, and had to be rebuilt, but even so many ancient terraces have lasted in good condition in a number of countries until the present time.

One of the most ancient and simplest ways to protect soil from erosion is soil tillage and placement of plant rows across the slope, a method used in ancient Rome. At present soil tillage across the slope or along the contour of the horizontal lines of the locality under cultivation is considered to be one of the fundamental elements of conservational soil treatment. An interesting detail is to be noted: almost two millennia passed between the first recorded use of tillage across the slope and the first application of contour tillage.

At present, however, these elementary anti-erosion practices are performed only on part of the total cropland area even in highly developed countries. For many centuries the negative effects of erosion actually went unnoticed by scientists and statesmen. Only in a number of European countries (Austria-Hungary, France, Germany and some others) were official policies adopted at government level to prohibit ploughing of mountain slopes and encourage afforestation of steep slopes and lands ruined by gullies. In general, there was neither investigation of surface water and wind erosion nor any developing and experimental testing of conservation practices on ploughed land.

It was only in the first quarter of the twentieth century that special experimental stations for the study of causes and mechanisms of erosion and deflation processes, and the mapping of eroded and deflated soils and their extension, were founded in the United States and a number of European countries. For the first time conservation farming practices started to be developed, and their effect on water runoff, water and wind erosion, and their impact on major crop yields experimentally were evaluated.

Information accumulated by researchers made it possible to objectively reveal the scope and harmfulness of erosion and deflation for agricultural production and the environment. The need to adopt conservation soil treatment was put on a firm scientific basis.

Currently a large number of anti-erosion (conservation) agro-technical, chemical, meadow-and-forest meliorative measures and hydro-technical constructions have been developed by world science and practice to prevent and reduce soil loss from erosion and deflation. In different natural zones, and under differing local conditions inside single zones, a varying number of different measures and practices may be used. The selection of particular methods depends on the specific genetic features of the soil concerned, its actual erodibility, the degree of dissection of relief by ancient and contemporary forms of scouring, peculiarities of how precipitation may lead to surface water runoff, the soil-protecting properties of crops, the intensity of erosion processes, and a number of other factors. But the efficiency of anti-erosion practices – or their combination (complexes) – will depend significantly on their proper location in the relief, that is, on the anti-erosion organization of the territory of a particular farm, river basin, or catchment of a ravine.

That is why anti-erosion organization of territory – laying out the borders of fields, crop rotations, and crops so as to reduce soil loss from erosion and increase productivity – must be performed in all zones where soil erosion is present and measures to protect soil from destruction by erosion processes are planned to be used.

9.3 Anti-erosion organization of territory

Anti-erosion organization of territory forms an organizational-economic unit of the whole complex of conservation farming methods, and is the foundation that creates conditions for an efficient managing system of producing and protecting natural resources. The territory organization (arrangement of agricultural lands) can be carried out by an agricultural enterprise or a private land user (landowner), either to an existing available model design that is suitable for the natural and economic conditions of the farm, or to a design can be ordered from a specialized design organization or service. Such arrangements are designed according to the requirements of national or local nature-protecting programs.

The range of problems to be solved includes the following:

- The natural and economic resources for agricultural production need to be analysed, along with the degree of their influence on specialization and technology of production. The forms and intensity of erosion processes must be estimated, taking into account the relief conditions, mechanical soil composition, precipitation and wind regimes, projective vegetative soil cover in erosion-prone and deflation-prone periods, the scale and effect of anthropogenic impacts on the anti-erosion resistance of soils, and the overall functioning of the agro landscape.
- Land areas must be classified by their intended use, warmth and moisture resources, duration of vegetation period, level of soil fertility, uniformity of meliorative impacts, and the intensity of predicted soil erosion in their planned use.
- The damage likely to be caused to production and environment erosion processes must be evaluated. The kinds and amounts of anti-erosion measures for each typological land allotment must be estimated, taking into account their role in the technological process of crop growing and the soil-protecting properties of crops themselves.
- The planned crops must be selected on the basis of the resources of the local landscape and its capacity to provide their physiological needs (which may be artificially supplemented by material and mechanical means).
- In the distribution of crop rotation fields, working plots must be created in areas with soils of similar quality. The size and the shape of these uniformed areas should be taken into consideration, as should the specific use of agricultural machinery. Pasture and hay land rotation plots, recreation and micro-reserve areas should be distributed on lands suitable for them.
- Linear borders must be laid out and coordinated, in the form of road networks and other communication lines, field borders, windbreaks, runoff controls, and other elements of the anti-erosion complex such as natural ephemeral streams, water-discharge and water-retention constructions.
- The plan for the projected measures must lay down the sequence in which individual elements of the anti-erosion complex will be introduced, and take account of landscape formations that are resistant to external uncontrolled impacts.

9.4 The principles of anti-erosion measures

The solution of these problems must be based on the adaptive-landscape approach to nature use, and on observation of a number of definite principles:

- Specialized production and cropping systems must conform to the natural conditions of the locality, bearing in mind its vulnerability to soil erosion and deflation. As little valuable land as possible should be used for anti-erosion constructions and measures.
- Soil protection should be provided if it is necessary by changing the structure of land use and introducing new crops.
- The resources and environment on every field and working plot should be made sustainable.
- Technological tillage methods should be combined with field management measures to protect soil from erosion and deflation.
- Machines and implements in a cropping system should be used in ways that do not exceed the agro-ecological limitations to technogenic loading on lands;
- The properties of crops should be used to the maximum to dissipate the energy of water and wind streams by means of complete and thick projective vegetative cover of soils in erosion-prone periods and to improve the anti-erosion resistance of soils.

The essence of the anti-erosion organization of territory is:

- Placement of linear borders across slopes and along contours. These borders may be forest belts, inner farm roads, or the borders of agricultural lands, crop rotations, and fields, which divide long slopes into shorter sections.
- Differentiated placement of crop rotations and use of technologies of crop growing that take account of soil fertility, the soil's vulnerability to erosion, and microclimatic conditions on slope elements.
- The use of the necessary field management and agrochemical measures between the linear borders on more erosion-prone slopes, and of hydro-technic constructions in the form of mountainous terraces with a wide base. These measures make it possible to reduce soil loss and scouring to tolerable levels, to raise crop yield, and to lower the ecological effects of erosion considerably.
- Work on the anti-erosion organization of territory is performed by specialized project organizations working to the specifications of an agricultural enterprise or a farmer. Soil-erosion maps on a scale of up to 1:10,000 are drawn up to show the basic watershed lines limiting the catchment area where the surface runoff of shower and/or snowmelt waters, soil wash, and scouring take place. On every watershed, slope sections of different steepness are singled

out so that the intensity of erosion processes can be analysed. Slope steepness can be determined in gradients, tangents of the inclination angle, or as percentage (Table 9.1).

On the cropland of the forest-steppe and steppe zones with gray forest and chernozem soils, slopes can be classified according to steepness: those with gradients up to 3, those between 3 and 5, and those above 5. These gradients are related to erosion processes, and grouping slopes by the degree of steepness adequately reflects the distribution of soils by fertility. On slopes up to a gradient of 3, full-profiled uneroded or slightly eroded soils predominate; on slopes of 3-5 grades there are slightly or middle-eroded soils; on slopes steeper than 5, moderately and severely eroded soils predominate.

In other climatic zones, and especially in mountainous and pre-mountainous areas, slope grouping by the degree of steepness and soil fertility can differ considerably from the one given above. However, in all cases classification must be based on the ratio of the intensity of erosion processes to the process of natural soil formation.

Borders of slopes that are different in their degree of steepness and soil erosion serve as borders for differentiated placement of crop rotations. Flat areas of watershed plateaus, and slopes with gradients of less than 3, which tend to have the most fertile soils and be slightly eroded, are allotted to the intensive type of crop rotation, in which row crops and fallow occupy up to 50-60% of the area. Slopes with gradients between 3 and 5 and mildly or moderately eroded soils, are generally used for grain–grass crop rotation with predominating grain cereals and annual grasses. Slopes with gradients of 5 or more, the least fertile soils, and intensively expressed erosion processes, require a grass and grain soil-protecting crop rotation in which up to 40-60% of the area is occupied by perennial grasses.

Table 9.1. Classification of slopes by the degree of steepness (Volodin et al., 2002)

Slope	Steepness	Inclination	
		tangent	percent (%)
Very flat	1	0.017	1,7
Flat	1 - 2	0.017-0.035	1.7 – 3.5
Slanding	2 – 5	0.035 – 0.087	3,5 – 8.7
Slanding -steep	5 – 9	0.087 – 0.158	8.7 – 15.8
Steep	9 – 20	0.158 - 0.364	15.8 – 36.4
Very steep	20 – 30	0.364 – 0.57.7	36.4 – 57.7
Extremly steep	30 - 40	0.577 – 1.00	57.7 – 100

9.5 Requirements on crop rotation

The following requirements apply to the placement of the borders of crop rotations, fields, and working plots in conditions of complex relief.

Individual crop rotations and crop rotation fields are placed on lands that are similar in their soil and relief conditions and uniform in the intensity of erosion processes. The long side of the borders of the rotation fields of working plots is placed across the slope or along the contour, similarly to the location of water-preserving forest belts, buffer strips of grasses and shrubs, field roads, and other linear borders, in order to serve as a guideline for soil tillage and crop planting.

The end borders of fields must align with gully tops or extend into ploughed dingles and hollows. Where suitable borders to homogenous areas cannot be established, because of slope steepness and the degree of soil erosion, small areas of less eroded lands are joined with the plots of more eroded lands, and less steep plots with steeper ones; and

On even, regular slopes, the parallel horizontal borders of crop rotations, fields, and all other linear borders are placed strictly across the slope, in other words along horizontal lines.

On prominent and concave forms of slope where their orientation relative to the cardinal points is different, it is often impossible to arrange borders and the like along the contours. Placement of linear borders along the horizontal lines in such cases would produce plots of different width and shape, and some parts of the area would be separated from the cropland. This would make soil tilling and crop cultivating, and the use of agricultural machinery, much more difficult. The technique of placing linear and other borders strictly along the horizontal lines is usually recommended for slopes with intensive soil loss and soil scouring.

For less erosion-prone lands on slopes, especially on the upper parts of the catchment contiguous to the flat watershed area, linear borders may be allowed to deviate from horizontal lines. To prevent soil loss and soil scouring, the length of linear borders and their secondary inclination must not be such as to allow water streams to reach above tolerable erosive velocities for individual soils and subsoils.

It is more difficult to perform the proper organization of territory in regions with complex relief and combined water erosion and deflation, since the direction of the winds that cause deflation is frequently different from the direction of streams of running water formed during snowmelt and shower rainfall. That contradiction is usually solved in the following way. On flat areas and contiguous slopes with gradients of up to 1 or 2, long field borders and wind-breaking forest belts are located across the direction of the winds. Within the fields, if necessary, additional measures are aligned in the same direction. These include buffer strips of high-stemmed grasses, strip planting of crops, and flat tillage with stubble being left on the surface.

When such conditions apply on more steeply sloping land, the requirements for the anti-erosion organization of territory and placement of linear borders remain the same as in regions where only water erosion occurs.

The final stage of anti-erosion organization of territory is planning for individual plots, rotation fields and the whole watershed, and implementing practical methods and practices and their combinations (complexes) to retain the expected water runoff, reduce soil loss to a tolerable level, prevent the formation of gullies, and prevent fertilizers and pesticides from slope lands from entering water reservoirs.

It is economically viable to design a complex of anti-erosion measures to retain snowmelt and rainwater runoff where there is a 10% probability, that is, a frequency of once in ten years. In areas where the frequency is less, anti-erosion organization will entail planning for emergency discharge of excess uncontrolled water runoff. On slopes under cropland such constructions usually take the form of un-ploughed depressions with natural grass cover, or artificial grassed waterways and steep concrete channels.

Sources of chapter 9

Sections 9.1-9.5 adapted from: Volodin V.M., Cherkasov G.N., Rozhkov A.G. and Pykhtin I.G., 2002: *Conservational Soil*

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Chapter 10
Wastewater Treatment and Use in Agriculture

10.1 Municipal waste water as a hidden resource

With increasing global population, the gap between the supply and demand for water is widening and is reaching such alarming levels that in some parts of the world it is posing a threat to human existence. Scientists around the globe are working on new ways of conserving water. It is an opportune time, to refocus on one of the ways to recycle water – through the reuse of urban wastewater, for irrigation and other purposes. This could release clean water for use in other sectors that need fresh water and provide water to sectors that can utilize wastewater e.g., for irrigation and other ecosystem services. In general, wastewater comprises liquid wastes generated by households, industry, commercial sources, as a result of daily usage, production, and consumption activities.

Municipal treatment facilities are designed to treat raw wastewater to produce a liquid effluent of suitable quality that can be disposed to the natural surface waters with minimum impact on human health or the environment. The disposal of wastewater is a major problem faced by municipalities, particularly in the case of large metropolitan areas, with limited space for land based treatment and disposal. On the other hand, wastewater is also a resource that can be applied for productive uses since wastewater contains nutrients that have the potential for use in agriculture, aquaculture, and other activities.

In both developed and developing countries, the most prevalent practice is the application of municipal wastewater (both treated and untreated) to land. In developed countries where environmental standards are applied, much of the wastewater is treated prior to use for irrigation of fodder, fiber, and seed crops and, to a limited extent, for the irrigation of orchards, vineyards, and other crops. Other important uses of wastewater include, recharge of groundwater, landscaping (golf courses, freeways, playgrounds, schoolyards, and parks), industry, construction, dust control, wildlife habitat improvement and aquaculture. In developing countries, though standards are set, these are not always strictly adhered to. Wastewater, in its untreated form, is widely used for agriculture and aquaculture and has been the practice for centuries in countries such as China, India and Mexico.

Thus, wastewater can be considered as both a resource and a problem. Wastewater and its nutrient content can be used extensively for irrigation and other ecosystem services. Its reuse can deliver positive benefits to the farming community, society, and municipalities. However, wastewater reuse also exacts negative externality effects on humans and ecological systems, which need to be identified and assessed.

Before one can endorse wastewater irrigation as a means of increasing water supply for agriculture, a thorough analysis must be undertaken from an economic perspective as well. In this regard the comprehensive costs and benefits of such wastewater reuse should be evaluated. Conventional cost benefit analysis quite often fails to quantify and monetize externalities associated with wastewater reuse.

Hence, environmental valuation techniques and other related tools should be employed to guide decision-making. Moreover, the economic effects of wastewater irrigation need to be evaluated not only from the social, economic, and ecological standpoint, but also from the sustainable development perspective.

Pakistan is a case which illustrates this problem. Both treated and untreated municipal wastewater in the vicinity of large cities like Faisalabad is used for vegetable production. But, how safe is this practice? How does one trade-off between the obvious benefits of this use and the costs associated with it?

10.2 Safe use wastewater in agriculture

Wastewater use in agriculture is much more commonplace than many believe. At present, approximately 20 million hectares of arable land worldwide are reported to be irrigated with wastewater. The unreported use of wastewater in agriculture can be expected to be significantly higher. It is particularly common in urban and peri-urban areas of the developing world, where insufficient financial resources and institutional capacities constrain the instalment and operation of adequate facilities for proper wastewater collection and treatment.

Wastewater use in agriculture has certain benefits, providing water and nutrients for the cultivation of crops, ensuring food supply to cities and reducing the pressure on available fresh water resources. However, wastewater is also a source of pollution, and can affect the health of users, consumers and the environment if safe practices are not applied.

While populations and urban areas are growing at unprecedented rates and water scarcity is increasing, it is expected that, in the near future, the use of wastewater in agriculture will increase further in areas where fresh water is scarce.

To address and promote safe practices where wastewater is used in agriculture, seven UN-Water members, partners and programmes have come together in a multi-year, multi sectorial project: the Food and Agriculture Organization of the United Nations (FAO), the World Health Organization (WHO), the United Nations Environment Programme (UNEP), the United Nations University Institute for Water, Environment and Health (UNU-INWEH), UN-Water Decade Programme on Capacity Development (UNW-DPC), the International Commission on Irrigation and Drainage (ICID) and the International Water Management Institute (IWMI).

The objective during this phase was to raise awareness among participating Member States and identify the capacity needs in their respective countries, so that further work can be done at the national level in order to develop and implement guidelines for safe wastewater use in their countries. When it comes to officially reported figures, information regarding the quantity of wastewater generated, treated and used at the national scale is often unavailable, limited, or outdated in numerous countries. Yet this kind of information is crucially important for policy-makers, researchers and practitioners as well as public institutions, if they are to develop national action plans aimed at wastewater treatment and the productive use of wastewater in agriculture, aquaculture and agroforestry that include environmental conservation and health protection measures.

While searching data and literature in published or electronic forms for 181 countries, Sato et al. (2013) found that only 55 countries have data available on all three aspects of wastewater – generation, treatment and use. The number of countries with one or two aspects of wastewater generation, treatment and use is 69, while there is no information available from 57 countries. Of the available information, only 37% of the data could be categorized as recent (reported during 2008 to 2012).

Information on untreated wastewater is even more difficult to estimate, as it largely goes unreported. Reliable data quantifying its use are scarce, but it is estimated that, annually, areas of around 20 million ha (7% of the total irrigated land) are under irrigation with untreated or partially treated wastewater, particularly in arid and semi-arid regions and urban areas where unpolluted water is a scarce resource. The water and nutrient values of wastewater represent important, drought-resistant resources for farmers (Scott et al., 2004). Research results reported by Raschid-Sally and Jayacody (2008) indicate that, on a global level, around 200 million farmers use treated, partially treated and untreated wastewater to irrigate their crops, including in areas where irrigation water is heavily polluted.

10.3 Agriculture water demands for urban food production

Water for irrigation and food production constitutes one of the greatest pressures on fresh water resources. The daily drinking water requirement per person is 2-4 litres, but it takes 2,000 to 5,000 litres of water to produce one person's daily food. Agriculture is by far the largest consumer of fresh water resources, currently accounting for over 70% of global withdrawals and 86% of the world's total fresh water consumption (FAO, 2012). In Africa and Asia, an estimated 85-90% of all fresh water resources are used for agriculture (UNEP, 2008). Figure 10.1 illustrates that, particularly in several countries in Africa and Asia, where water is an increasingly scarce resource, agricultural water withdrawals already exceed 90% of total water withdrawals. Unprecedented population growth and shifts in dietary habits will increase food consumption in most regions of the world. By 2050, due to an estimated additional production of one billion tonnes of cereals and 200 million tonnes of meat needed to satisfy growing future food demand, global agricultural water consumption – both rainfed and irrigated agriculture – is expected to increase even further, by 19% (WWAP, 2012).

Of all economic sectors, agriculture is particularly sensitive to water scarcity. Steadily increasing demand for agricultural products is the main driver of agricultural water use. In particular, in the cities of the developing world, where almost all world population growth will occur, food demands will increase accordingly.

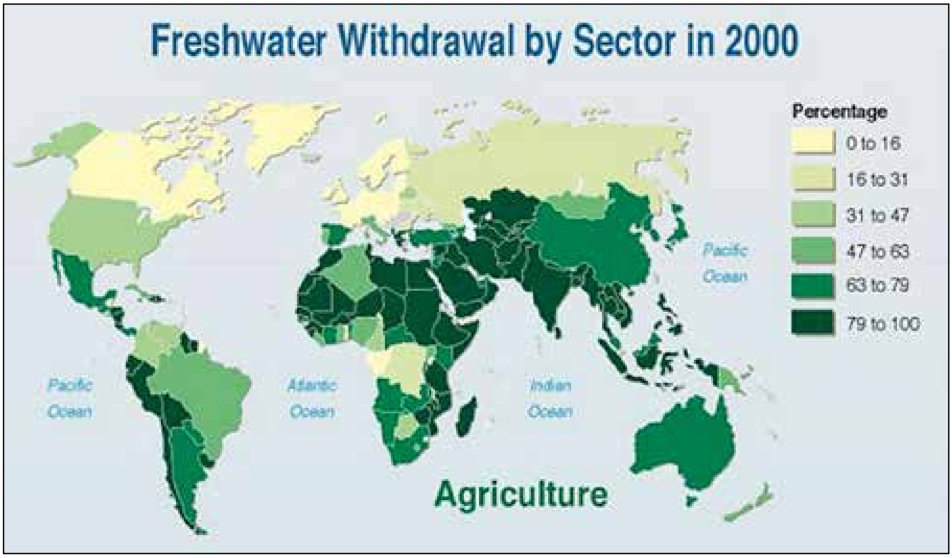

Figure 10.1. Freshwater withdrawal by sector in 2000 (Philippe Rekacewicz, UNEP/GRID-Arendal)

Urban and peri-urban agriculture play an important role in compensating rising food demands and supplying food products to the cities. Hence, agricultural activities need to be intensified to reach higher production levels, which require large amounts of additional water for irrigation. In areas with water-stressed conditions, where fresh water – due to population growth, urbanization and climate change – is becoming increasingly scarce and water supplies remain fixed, untreated or partially treated wastewater, of which larger volumes are produced, is increasingly being used for irrigation and will become the sole water source for many farmers (WHO, 2006). It is estimated that 10% of the world's population relies on food grown with contaminated wastewater (Corcoran et al., 2010).

10.4 Is agricultural water safe?

Water quality can be affected by poor planning of industrial sites, animal farms, and barnyards and feedlots. Until recently, the type of water source has been indicative of the potential risks of contamination. Poor water quality can affect the quality of food crops and lead to illness in those who consume them. For example, the water may contain germs that cause human disease. Irrigating crops with contaminated water can then lead to contaminated food products which lead to illness when eaten. Groundwater, for example, has been considered one of the safest sources of water. However, depending on field location and field size, it may not be possible to use water from these sources for irrigation.

Agricultural water is water that is used to grow fresh produce and sustain livestock. The use of agricultural water makes it possible to grow fruits and vegetables and raise livestock, which is a main part of our diet. Agricultural water is used for irrigation, pesticide and fertilizer applications, crop cooling (for example, light irrigation), and frost control. According to the United States Geological Survey (USGS), water used for irrigation accounts for nearly 65% of the world's freshwater withdrawals excluding thermoelectric power. There are 330 million acres of land used for agricultural purposes in the United States that produce an abundance of food and other products.

10.5 Where the agricultural water comes from

Agricultural water comes from a variety of sources. Typical sources of agricultural water include:

- Surface water: Rivers, streams, and irrigation ditches
- Open canals

- Impounded water such as ponds, reservoirs, and lakes
- Groundwater from wells
- Rainwater
- Locally collected water such as cisterns and rain barrels
- Municipal water systems such as city and rural water can also be used for agricultural purposes.

When agricultural water is used effectively and safely, production and crop yield are positively affected. A decrease in applied water can cause production and yield to decrease. Management strategies are the most important way to improve agricultural water use and maintain optimal production and yield. The key is to implement management strategies that improve water use efficiency without decreasing yield. Some examples include improved irrigation scheduling and crop specific irrigation management. These strategies allow for the conservation of water and energy, and decrease grower's costs.

10.6 Potential and actual irrigated areas

The area equipped for irrigation is worldwide in 2012 over 324 million hectares, of which about 85% or 275 million ha are actually irrigated. Irrigated agriculture

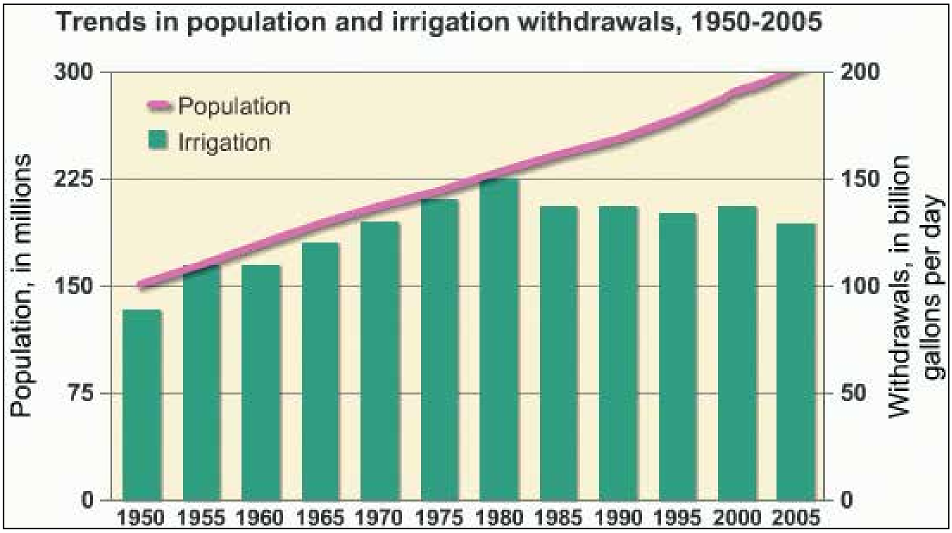

Figure 10.2. Trends in population and irrigation withdrawals in USA, 1950 – 2000 (https://water.usgs.gov/edu/wuir.html)

represents 20% of the total cultivated land, but contributes 40% of the total food produced worldwide.

Sub-Saharan Africa is the region with the lowest portion of the cultivated area that is irrigated, just over 3% against almost 21% at global level. At the same time it has the highest prevalence of undernourishment, 25% in 2011-2013 against 12% at global level.

Irrigation – in conjunction with high-yielding varieties, inputs such as fertilizers and pesticides, and the use of agricultural machinery – played a significant role in the green revolution in Asia. At present, 41% of the cultivated land is under irrigation against 26% in 1970, contributing to a considerably reduction of its undernourishment from 24% in 1990-92 to 14% in 2010-12.

The greatest potential for expanding irrigated agriculture, considering both land and water resources, is in the Sub-Saharan Africa region, where only one fifth of the irrigation potential has been equipped, or 7.7 million ha out of a potential of 38 million ha, and in the Southern America region, where only one fourth of the potential has been equipped, or 16 million ha out of a potential of 60 million ha.

Over 88% of Central Asia's and Northern Africa's irrigation potential has already been equipped, 69% in the Middle East and 65% in the Southern and Eastern Asia region. The Asian continent, with almost 230 million ha equipped for irrigation, represents just over 70% of the irrigation area worldwide. Almost 60% of these 220 million ha – or 42% of the world total – is located in only two countries, China and India, where also almost 40% of the world population is located. Asia is also the continent benefiting the most of its irrigation infrastructure, with the largest part of area equipped for irrigation that is actually irrigated (89%).

In Europe the part of area equipped for irrigation actually irrigated, 65%, is low compared to the rest of the world. This is due to a moderate climate in a large part which allows agriculture to benefit from the available precipitation and thus not always needing to be irrigated.

Localized and sprinkler irrigation account for about 14% of the total area equipped for irrigation worldwide. Localized irrigation has grown rapidly since the invention of cheap plastic pipes in the 1970s: from almost 0.5 million ha in 1981 to almost 9 million ha in 2010 worldwide.

Sprinkler irrigation equips more than 35 million ha in 2010. Although considered less efficient than localized irrigation, both its cheaper prices and potential mobility explain its wider expansion.

Most irrigation in the Northern America region uses groundwater (59% of its irrigated area). While groundwater is the only reliable source of water in arid

1 m^3 = 1,000 litres = 35.3 cubic feet = 264.17 US gallons
1 litre/m^2 = 10 m^3/hectare = 10,000 litres/hectare = 350.3 cubic feet/hectare = 2,640.17 US gallons/ha

countries, in countries with moderate climatic conditions it is often used in conjunction with pressurized irrigation equipment or when electricity is subsidised (reducing pumping costs).

China is the country with the largest area equipped for irrigation, 69.4 million ha, immediately followed by India with 66.7 million ha. Outside the Asian continent, the countries with the largest irrigation areas are: the United States of America in the Americas with 26.4 million ha, Italy in Europe with 3.95 million ha, Egypt in Africa with 3.65 million ha and Australia in Oceania with 2.55 million ha. In 2010, China became the country with the largest irrigation area, overtaking India which ranked first for over 50 years.

Irrigation is not limited only to the dry periods of the year. In numerous countries, supplementary irrigation is also taking place during the rainy season – for example in Myanmar for rice cultivation – to make up rainfall deficits during critical stages of the crops in order to stabilize or increase yields.

Irrigation is known to have been practised already more than four thousand years ago. The Euphrates and Tigris rivers were the cradle of the early Mesopotamian civilizations and irrigation with their water made development of agriculture possible. In Egypt, floodwater from the Nile was already used for cultivation during pharaoh period. In Mongolia, irrigation was probably developed under the Huns in the first century of the current era.

At least 111 million ha equipped for irrigation use a pump for water supply from the source to the field. One single irrigation scheme can cover over 10 000 ha in some countries such as in India, Mexico, Pakistan and Sudan for example. At least 33 countries have implemented an irrigation management transfer in order for the management of the irrigation schemes to be transferred from the government to the irrigators or water users.

In 2011, over 346 million ha of irrigated crops were harvested from the 261 million ha actually irrigated. Indeed, thanks to irrigation and if climate is favourable more than one crop cycle is permitted each year on the same area, resulting in a global cropping intensity for irrigated crops of over 130%. Irrigation contributes to 40% of crop production worldwide on 20% of the world’s cultivated area that is equipped for irrigation.

The climatic conditions allowing various cropping cycles in a year in large parts of Asia, Africa and Americas, make a significantly larger cropping intensity possible in these regions than in parts of Europe and Oceania, where irrigated crop growth in the winter season is little or non-existent. Asia is the continent with the highest irrigated cropping intensity (141%), going from just over 100% in Central Asia, where cropping in winter season is limited, to more than 170% in large parts of the Southern and Eastern Asia region. The combination of high cropping intensity and high rates of areas equipped for irrigation actually irrigated makes that Asia and Africa benefit the most of irrigation. In Burkina Faso, irrigated agriculture contributes significantly to food security: irrigation produced in 2010 around 10% of the total agricultural production for only 1% of the cultivated area. 78% of the world's harvested irrigated crops area is in the Asian continent.

Over 60% of the irrigated area worldwide is dedicated to cereals; Asia hosts 87% of the irrigated cereals areas. Rice is the world's largest irrigated cereal, covering 47% of irrigated cereals area. Rice is also the main irrigated crop worldwide, covering 29% of the total irrigated crop area.

Oceania is the only continent not dominated by irrigated cereals, which represent only 13% of the irrigated crop area. There, irrigated fodder and pastures represent almost half of the irrigated crop area (48%). At a smaller scale, the latter also largely prevails (51%) over irrigated cereals (17%) in the Eastern Europe and the Russian Federation.

Diversification of irrigated crops is higher in countries with higher income, where the relative importance of irrigated cereals becomes less: the part of cereals in irrigated crop area is respectively 75, 64 and 38% in low-, middle- and high-income countries.

With 76% of the irrigated areas of the least developed countries dedicated to cereals, irrigation there focuses on provision of staple food. In high-income countries vegetables, fruits, oil crops, and fodder and pasture diversify the irrigated crops, together covering more than half of the irrigated area, against just over 10% in the least developed countries.

10.7 Irrigation efficiency

The world's water requirement ratio, sometimes also named irrigation efficiency – that is the amount of water required for irrigated crops over the volume withdrawn for irrigation – is around 56%, varying from 23% in areas of abundant water resources (Central America region) to 72% in the Northern Africa region where water scarcity calls for higher efficiency. In addition to geographical disparity, the ratio also depends on financial resources availability. It increases from 48% in low-income countries to 56% in middle-income countries and 61% in high income countries.

Almost the entire crop production is from irrigated land in Djibouti, Egypt, Kuwait, Oman, Qatar, Saudi Arabia, Tajikistan, Turkmenistan, United Arab Emirates and Uzbekistan. Rainfed agriculture in these arid countries is not reliable because of low precipitation. At a global scale, 7,700 m^3 of water per hectare is withdrawn on average annually for irrigation. In addition to the regular crop water requirements, a layer of 10-20 cm of water is required for flood paddy rice, the world's largest irrigated crop, for land preparation and plant protection.

Drainage facilities, in delta areas in particular, are considered as a form of flood protection. In conjunction with irrigation they also prevent waterlogging and salinization. The area salinized by irrigation covers over 37 million ha worldwide, thereby reducing productivity.

Overexploitation of groundwater when water withdrawal exceeds water recharge – and its subsequent lowering of water tables – is a recurring problem in the Arabian Peninsula and the Near East. It also often leads to seawater intrusion in coastal areas, drastically deteriorating the quality of groundwater. In India's Tamil Nadu state, over pumping – amongst others due to subsidizing electricity

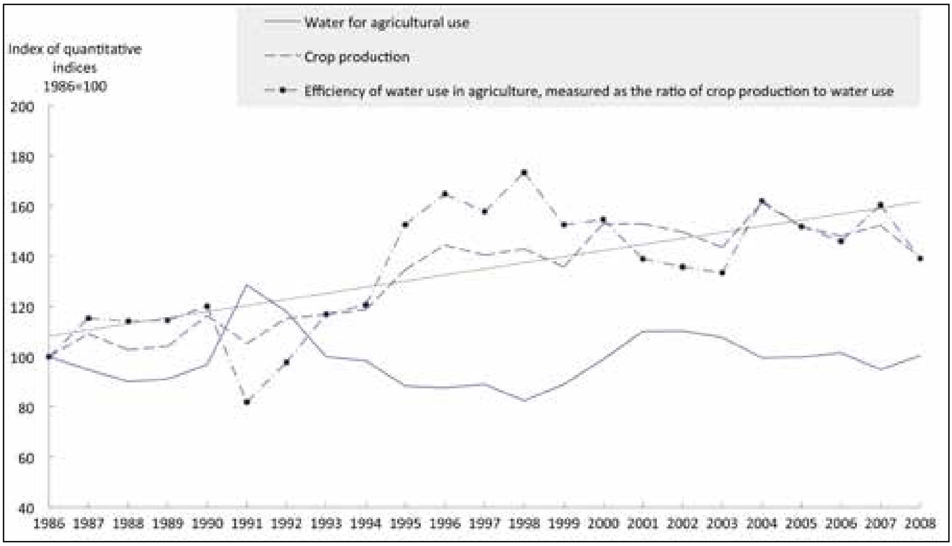

Figure 10.3. Relation between efficiency of water use in agriculture and crop production (OECD 2010b)

Box 10.1 Uzbekistan – Irrigated crop calendar

UZBEKISTAN
Irrigated crop calendar 2005

Irrigated crops	Irrigated area	Crop area as percentage of the full control actually irrigated area by month											
	1000 ha	J	F	M	A	M	J	J	A	S	O	N	D
Wheat	1 295	35	35	35	35	35						35	35
Rice	52				1	1	1	1	1				
Barley	48	1	1	1	1							1	1
Maize	25				1	1	1	1	1				
Vegetables	137				4	4	4	4	4				
Fruit	200	5	5	5	5	5	5	5	5	5	5	5	5
Potatoes	37	1	1	1	1	1							
Fodder temporary	300	8	8	8	8	8						8	8
Fodder permanent	100	3	3	3	3	3	3	3	3	3	3	3	3
Cotton	1 406				38	38	38	38	38	38	38		
Pasture permanent	100	3	3	3	3	3	3	3	3	3	3	3	3
Harvested irrigated crop area [AHI_{full}]	**3 700**	**56**	**56**	**56**	**100**	**99**	**55**	**55**	**55**	**49**	**49**	**55**	**55**
Area equipped for full control irrigation actually irrigated [AAI_{full}]	**3 700**												
Cropping intensity (%) = 100 x [AHI_{full}]/[AAI_{full}]	**100**												
Area equipped for full control irrigation [AEI_{full}]	**4 198**												
% of full control equipped actually irrigated = 100 x [AAI_{full}]/[AEI_{full}]	**88**												
Total area equipped for irrigation [AEI_{tot}]	4 198												

AEI_{tot} and AEI_{full} are equal to 4,198,000 ha and AAI_{full} is equal to 3,700,000 ha in 2005 (FAO, 2012a). AHI_{full} is assumed to be identical to AAI_{full}. A partial AHI_{full} is 2,753,000 ha (Adbullaev et al. , 2009; FAO, 2012b). It has been completed by adding estimated areas for other crops in order to obtain a cropping intensity of 100 percent. By far the main irrigated crops are cotton and wheat. Some rice, maize, barley, potatoes, vegetables, temporary and permanent fodder, fruits and permanent pastures are also irrigated. Temporary crops are either irrigated in summer from April to August (or to October for cotton) or in winter from November (or January for potatoes) to May (such as wheat, barley and temporary fodder).

Source: Frenken K., Gillet V., 2013 Irrigation water requirement and water withdrawal by country. FAO AQUASTAT Reports

thus reducing pumping costs – has lowered the water level in wells in certain areas by 25 to 30 metres in one decade.

Almost 155 million ha are under conservation agriculture worldwide. Despite not using irrigation technologies as such, this technique enhances water use efficiency in rainfed conditions thanks to minimum soil disturbance (no tillage), soil cover and appropriate crop association.

Some wetlands and inland valley bottoms are cultivated with minimum disturbance to the environment, as they have no or limited (mostly traditional) equipment to regulate water and control drainage. Flood recession cropping is another traditional water management technique with relatively low environmental impact, where cultivation occurs along rivers in the areas exposed as floods recede

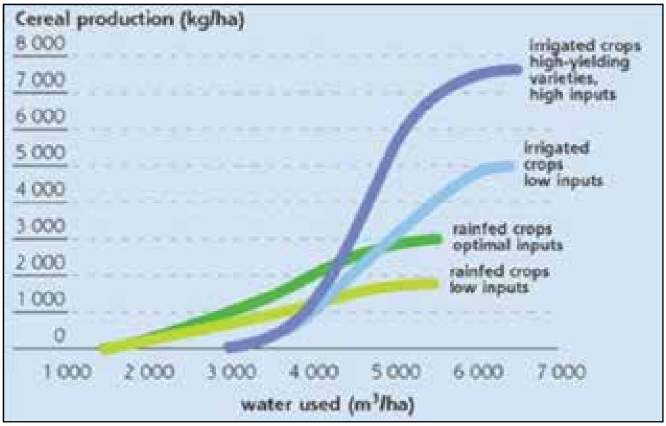

Figure 10.4. Influence of agriculture and irrigation strategies technology for water use and cereal production (OECD 2010)

and where nothing is undertaken to retain the receding water. Over 8.6 million ha worldwide are cultivated with these traditional forms of water management.

The drying up of the Aral Sea in Central Asia is one of the most dramatic examples of environmental tragedy caused by the mismanagement of irrigation: the sea level dropped by 17 meters and the shoreline moved 70 km since 1960s. This is due to the large diversions of water for irrigation of cotton and electricity production, resulting in little water reaching the Aral Sea. On a positive side, without the high productivity permitted by irrigation, at least an additional 500 million ha would be needed to reach the current agricultural production. Temperate or humid areas allowing rainfed production are often already densely populated or environmentally disturbed, therefore having no additional land for agriculture available anymore. Currently, countries reaching their limit of cultivated areas already buy or rent large areas in other less intensely developed countries, also known as land grabbing.

Globally more than one third of the food is lost between field and fork, and thus also a large amount of water, needed to produce the food. While in poor countries most losses occur due to post-harvest losses, in rich countries losses are mainly due to throwing away the food that is not consumed.

Sources for Chapter 10

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Chapter 11
Distribution of Irrigated Lands and Water Consumption

11.1 Extent of irrigation

At the end of the twentieth century the world's irrigated land comprised 2.72 million km^2 (272 million hectares) and about 60% of this belonged to four countries: India, China, the United States, and Pakistan. Irrigation of agricultural lands is one of the main causes of water consumption in the world, along with other human activities such as industry, transport, and domestic use. During the last decades of the twentieth century, irrigation worldwide consumed about 2,500 km^3 of fresh water annually, or approximately 70% of the total human use of this natural resource.

The practice of irrigation may have negative ecological impacts, including the exhaustion or contamination of natural water resources. Irrigation is required where and when precipitation is insufficient. The main function of water use by plants is to prevent overheating, especially during hot days. The water absorbed from soil by plant roots is mainly lost to the atmosphere through evaporation from plant leaves. Irrigated lands occupy about 18% of the total cultivated agricultural land worldwide and yield about a third of the global agricultural crop production.

The principal crops are grains (mainly rice and wheat), cotton, oil crops (e.g. soybeans), vegetables and fruits. Taking into account the growing global demand for food and raw industrial materials and the corresponding need for more irrigation water (approximately an additional 60 km^3 of water per year by 2025), future conflicts among water users are certain to occur, especially in regions where water is a scarce resource. According to predictions developed by the International Water Management Institute, a third of the world's population will experience severe water scarcity by the year 2025, which will likely be a destabilizing force for the development of some countries. Fortunately, there are a number of ways to reduce water consumption and negative ecological impacts in irrigated lands.

11.2 History of irrigation

It is well known that water is as important as air and food for mankind. Therefore, the history of the development of human society cannot be separated from the issue of water conservation. Historically, civilization has followed the development of irrigation. As the FAO has acknowledged "the early story of irrigation developments is buried in the oblivion of ancient unrecorded history. Since civilizations have risen on irrigated lands, the antiquity of irrigation is well documented throughout the written history of mankind."

One of the oldest citations is in the Bible. Genesis mentions Amraphel, King of Shinar, a contemporary of Abraham, who developed the "laws of Hammurabi," which indicate that the people had to depend upon irrigation for existence.

Further mention of irrigation is found in Second Kings 3:16-17: "And he said, Thus saith the Lord; Make this valley full of ditches. For thus saith the Lord, Ye shall not see wind, neither shall ye see rain; yet that valley shall be filled with water, that ye may drink, both ye, and your cattle, and your beasts." Irrigation canals believed to have been built under an ancient Assyrian Queen, who supposedly lived before 200 BC, are still delivering water today. Thus, there are records and evidence of continuous irrigation for thousands of years in the valleys of the Nile and for comparatively long periods in Syria, Persia, India, Java, and Italy.

Egypt claims to have the world's oldest dam, built 5,000 years ago, which is more than 100 meters long and 12 meters high, and is used to store water for drinking and irrigation. Irrigation introduced on the Nile about 3,300 BC "still plays an important part in Egyptian agriculture."

The 4,000 years of written records of the irrigation systems on the Tigris, from 2,600 BC to 1,400 AD, have been studied jointly by the Director-General of Antiquities in Iraq and the Oriental Institute of the University of Chicago. They include a series of recorded disasters from salinization. Salinity surveys are recorded from about 2,400 BC. Control of salinization by leaching and drainage appears to have been practiced.

The history of irrigation, drainage, and flood control in China can be dated back over 5,000 years, nearly 3,000 years of which is recorded history. In China flood control work began in about the twentieth century BC. In the early stages of the first century BC, the great litterateur Sima Qian wrote a special volume entitled "Hequshu," in his historical works "Shiji." It was a record of the rivers and canals. In the book he recorded the important events of water conservancy from the flood control works of the Great Yu in the twentieth century BC to his own time. After describing in detail the closure of a breach on the Yellow River ordered by Emperor Hanwu, he exclaimed: "What a role the water plays in the people's life whether it is beneficial or harmful."

After him, the tradition of keeping special historical records about water conservancy continued for more than 2000 years to the present. These records supply a rich experience of water conservancy for our work in this day and age. The famous

Tu-Kiang Dam, still an effective dam today, was built by a man named Mr. Li and his son in the Chin dynasty (200 BC) and still provides irrigation water for more than 2,000 km^2 (200,000 hectares) of rice fields. The water ladder, a widely used pumping device in China and neighbouring countries, is believed to have been invented about the same time. Country carpenters worshiped its inventor as a god. The Grand Canal, 1,125 meters long, was built in the Sui Empire, AD 589-618.

India also has a long history of irrigation. There are reservoirs in Sri Lanka, to the south of India that are more than 2,000 years old. Writings in 300 BC indicate that the whole country was under irrigation and very prosperous because of the double harvests that the people were able to reap each year. Wells, tanks, and inundation canals from rivers were well-known sources of irrigation water in India thousands of years ago.

11.3 Recent developments

More recently, at the beginning of the sixteenth century, the Spaniards on their entrance into Mexico and Peru found elaborate provisions for storing and conveying water supplies that had been used for many generations. Their origin was almost lost even to tradition. In the southeast of Mexico, the remains of canals and drains were found close to the ruins of Edzna, from the antique Maya culture. By the middle of the fifteenth century, Netzahualcoyotl, King of the Chichimecas, poet and engineer, constructed dams, canals, and flood control works in the Valley of Mexico. Some of these constructions can still be seen today close to the city of Texcoco.

Extensive irrigation works also existed in the southwestern United States. The early Spanish missionaries brought knowledge of irrigation from their Mediterranean homes. Trappers, miners, and frontiers people in many places in the western United States practiced irrigation also, although no effort was made to develop an agricultural economy based on irrigation until the Mormon Pioneers entered the Salt Lake Valley in northern Utah in July 1847.

Even though irrigation is as old as civilization itself, until the beginning of the nineteenth century the number of works built and the irrigated areas of the world were of relatively minor significance as a total part of agriculture. It has been estimated that the total irrigated area in the world was then about 80,000 km^2. But during the early part of the nineteenth century a number of fairly large irrigation projects were constructed in different parts of the world. In the latter half of the nineteenth century, there was considerable development of irrigation in India. Among the important works constructed, those worthy of mention include the Ganga canal completed in 1854, and the Godavari and Krishna Delta

Systems completed towards the end of the century. The Lower Chenab Canal (now in Pakistan) was built in the 1890s, and in addition a large number of inundation canals on the Indus and its tributaries were improved and extended. In the western United States numerous small irrigation works were built, mainly by private enterprise. Among these may be mentioned the efforts of the Mormons in Utah, the Greely colony in northeastern Colorado, and the Anaheim community in southern California. In Italy, the Cavour canal was built in 1852, followed by the Villoresi and Mariano canals, which were built between 1887 and 1891.

It has been estimated that the total area irrigated in the world by the end of the nineteenth century was about 400,000 km^2. In other words, the irrigated area was five times as large as at the beginning of the century. The more important developments of the century, however, were advances in the science of hydraulics and the development of techniques in the planning, construction, and operation of large projects. By the turn of the century, millions of hectares of once desert lands had been converted into green fields, new towns had appeared, and there was new life where there had been little before.

In the early years of the twentieth century irrigation planners began to develop very large-scale projects to improve agriculture production as well as to populate wastelands. New types of machinery, new methods of construction, new advances in hydraulics, and new developments in large dam construction all contributed to transforming agricultural production. Irrigation acreage increased at an exponential rate.

11.4 Present situation

World agriculture is the main consumer of fresh water, using significantly more than other activities such as industry and transportation. In recent decades the irrigation of fields has annually consumed about 70% of all the fresh water used by humans. The irrigated area of the world and fresh water consumption in irrigated fields increased significantly during the twentieth century (Table 11.1).

By the end of twentieth century, the irrigated area of the world covered about 18% of the cultivated total and contributed about a third of the world's food production. In some countries, like Egypt, China, and Pakistan, irrigated lands contribute much more than 50% of the national food production, as shown in Table 11.2. Irrigation contributed to the eradication of famine in the countries with the biggest populations, such as China, India, and Pakistan. In 2012 over 324 million hectares are equipped for irrigation.

Table 11.1 Development of irrigated area and annual water consumption for irrigation in world (FAOSTAT)

Year	Area (Million ha)	Volume of water use for irrigation (km^3)
1800	8	75
1900	48	450
1950	94	865
1960	140	1288
1970	198	1822
1985	250	2300
1995	267	2459
2000	272	2502
2012	275	

Table 11.2 Contribution of irrigation to food production in selected countries

Country	Irrigated area/Cultivated area	Food production in irrigated lands/Total country food production
Egypt	100	100
Pakistan	65	80
China	50	70
Chile	35	55
Peru	35	55
India	30	55
Mexico	30	55
Indonesia	40	50

Table 11.3. Irrigated area of principle groups of agricultural crops in the world at the end of the twentieth century. Source: FAOSTAT.

Crops	Area (Million ha)	Area (%)
Cereals	175	64.4
Oil seeds	19	6.7
Forage and Fodder	17	6.4
Fruits	16	6.0
Vegetables	15	5.6
Leguminoues	9	3.4
Sugar crops	4	1.5
Other crops	17	6.0
Total	272	100

Table 11.4. Principal consumers of wastewater for irrigation in 1990. Sources: Duncan and Cairncross (1990); FAO UNESCO (1997).

Country or region	Area (Million ha)
China	1.33
Central Asia (Aral Sea Basin)	0.70
Mexico	0.34
India	0.09

The most important irrigated crops in the world are a range of cereals (such as rice, wheat, corn, sorghum, and barley), forage grass (principally alfalfa), cotton, vegetables, and some orchard produce. Rice is the most important irrigated crop in the world. It occupies about 45% of the world's irrigated area. In China almost two-thirds of the national irrigated area is used for rice (paddy fields). The distribution of the principle irrigated agricultural crops in the world is presented in Table 11.3.

Since the late 1970s the expansion of irrigated land has slowed down markedly. This has occurred for several reasons, including low prices for food commodities and comparatively high energy costs. In addition, the general economic conditions since the middle of the 1980s have discouraged agricultural investment.

A related cause of the slowdown was that the rising cost of irrigation capacity growth in many countries made it harder to justify investments in irrigation on economic grounds. At the same time, increasing water scarcity, overexploitation of aquifers, and problems related to the drainage and salinity of irrigated lands have also reduced the growth of the irrigated area. The production of such important crops as cereals and fibres (principally cotton and linen) in irrigated lands decreased towards the end of twentieth century because their price was falling (in comparison with escalating energy prices), and investment in new irrigated areas diminished.

Some irrigated lands also use wastewater from sewage, agricultural runoff, or municipal supplies, in treated or even untreated form (but diluted with fresh water) (see Table 11.4).

Drainage water or runoff from irrigated lands is the principal type of agricultural sewage water. Wastewaters are frequently used for irrigation because of the growing deficit of fresh water, the high cost of agricultural fertilizers, and the presence in wastewaters of organic matter and plant nutrients such as nitrogen, phosphorus, and potassium.

At the end of the twentieth century, Central Asia was reportedly the primary region where agricultural runoff water was being re-used for irrigation, with an estimated 4,500 km^2. An additional 2,500 km^2 is irrigated with domestic and industrial wastewaters.

Sources chapter 11

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Chapter 12
What Do We Learn From Earlier Failures? The Case of the Aral Sea

12.1 Introduction

Perhaps the most extreme contemporary example of the potential negative impacts of agriculture is the drying of the Aral Sea due to the expansion of irrigation networks in the Soviet era. Climate in the region is hot and dry, and agriculture is highly dependent on irrigation. The predominant system in Uzbekistan consists of rotations of cotton planted in the spring (April-May) with winter wheat planted around the cotton harvest (October-November). In this paper, we build on our experience and research done in the region to suggest changes in the prevalent agricultural system to improve food security, sustainability and resilience. Considerable efforts and resources have been allocated towards new forms of water governance at the inter-state level to water user associations. We believe that in addition to such measures, changes in the cropping system are necessary, specifically to lessen Uzbekistan reliance on cotton. Introducing legumes as double crops following the harvest of winter wheat (from July to October) can provide a first transition step towards greater crop diversification which does not interfere with the State prescribed quotas on cotton and winter wheat. Appropriate investments in the repair of the irrigation and drainage infrastructures are also urgently needed.

12.2 Current challenges

Once the fourth largest inland water body, the Aral Sea level has dropped 17 m and has lost more than 74% of its area and 90% of its volume. It is now divided into three parts, the Small Aral Sea in the North, and two large basins (Eastern and Western) in the South. It has been estimated that the amount of water inflow that would be required to restore the Aral Sea to its original size is 50 km^3 year-1, a little less than half of the total annual renewable available water (Bortnik, 1999; Micklin, 2000). At the moment, inflows into the Sea are approximately 4 to 5 km^3 year-1from the Syr Daria river into the Small Aral Sea, and from 0 to 7 km^3/year for Amu Darya into the Large Aral Sea (Micklin, 2007). Since such an increase in inflow into the Sea is unattainable considering the importance of agriculture (and therefore of irrigation water) in Central Asian economies, many have accepted the death of the Aral Sea as it once was (Aladin et al., 2005). In the North, the Kazakh authorities with the help of the World Bank have constructed a dam to retain water in the Small Aral Sea. This has allowed a considerable increase in the

Small Aral Sea level, a decrease in salinity and the resurrection of the commercial fisheries with the current inflows. In the South, Micklin and Aladin (2008) have suggested to retain the water in the Western Aral Sea, which is deeper and thus has lower evaporation losses. They predict that the maintenance of the western Aral Sea would necessitate slightly more than 8 km^3/year, a much more attainable goal.

Furthermore, land degradation is now obvious throughout the basin. It is estimated that between 1990 and 2000 the proportion of the irrigated area affected by salinization has increased from 25 to 50% (EC-IFAS, 1999; Savoskul et al., 2004). Water is used to leach the salts out of the soil, but this in turn increases the salinity of the drainage water and its quality decreases for downstream uses. In order to leach salts away successfully drainage systems are necessary. Unfortunately, although 93% of the irrigated area has installed drainage, 32% of the open ditches are out of order, 46% of the subsurface drainage systems are no longer functional and all of the vertical drainage systems are broken (Dukhovny et al., 2007).

At the same time, climate change is introducing a new level of uncertainty. The limited information available points to predicted temperature increases of 1.5 to 2.75 °C (Ragab and Prud'homme, 2002).

Precipitations are also predicted to increase, but the increase in evaporation due to higher temperatures might more than offset higher rainfall and result in lower soil moisture. In addition, glaciers in the Himalayas are an important source of water for the two main rivers. There is evidence from modelling (Savoskul et al., 2004) and from satellite data (Khan and Holko, 2009) that the inflows have been increasing in recent years, but that the snow depth and snow cover area have decreased. Thus, it becomes urgent that new agricultural systems be adopted to decrease irrigation withdrawals, and ultimately decrease the dependence of agriculture on irrigation water.

12.3 Possible solutions – change of crops

On-farm water saving technologies will play an important role in improving the sustainability of agricultural systems in the region. Surface irrigation is the most widely used irrigation technique and will likely remain so in the future.

Technologies such as regulated deficit irrigation and alternate furrow irrigation are appropriate and do not demand capital investments. Through regulated deficit irrigation, growers allow some degree of water stress to be experienced by the crop in order to allow an increase in the area irrigated (Pereira et al., 2002; Kijne et al., 2003). Alternate furrow irrigation consists in supplying water to every second furrow, possibly alternating furrows between irrigation events to encourage root growth (Kang et al., 2000). Both of these techniques have been shown to increase substantially the water use efficiency in cereal crops. We have also demonstrated that both of these techniques, separately but particularly in combination, can be used to grow legume crops (common bean and mungbean) after the harvest of winter wheat in Uzbekistan (Webber et al., 2006; Bourgault et al., 2010a): in 2004, yields of common bean were not significantly decreased from reducing irrigation events from 5 to 3, while yields of mungbean were highest with a single irrigation event at flowering.

Water consumption for these two crops were 1500 and 2,200 m^3/ha for mungbean and common bean respectively including a pre-planting irrigation. In comparison, average water consumption for winter wheat and cotton are 4,790 and 7,070 m^3/ha respectively (EC-IFAS, 1999). In another experiment, we grew a soybean crop (also after the harvest of winter wheat) with approximately 2,500$m^3 ha^{-1}$ (Bourgault et al., 2000b).

Horst et al. (2007) have demonstrated water savings of 44% or 3,900 m^3/ha in cotton by using surge-flow irrigation (where irrigation water is delivered in interrupted high-rate pulses) with alternate furrow irrigation. If such savings were realized over the entire cotton growing area (approximately 1 million ha), and assuming that part of this water would be diverted to another 1 million ha in (for example) mungbean production, this would still leave 2,400 m^3/ha (or 2.4 km^3/year) of water saved for ecological purposes. Such calculations are obviously crude and simplistic, but they do point to real opportunities for the improvement of agricultural water use efficiency and crop diversification.

The diversification of agricultural products and a shift from cotton towards less water-intensive and more salt tolerant crop have been suggested before (Kotlyakov et al., 1992; Spoor, 1993). Growing legumes and exporting them could represent a real alternative to cotton for foreign currency for the Uzbek government.

Export markets could be developed and boost the agricultural sector, but will require state intervention and political will. The current system for cotton is well organized from the legacy of the communist system and could be modify to include other non-perishable crops such as dry grains. There exists a small but growing international market for mungbean used for sprouting or processing.

Australian farmers have started growing mungbean recently but most of this production is only suitable for processing. Mechanized agriculture cannot at this moment compete with the quality obtained by hand harvesting. As such, Uzbek mungbean would have a market advantage. Spoor (1993) suggested the development of fruit and vegetable export markets and we agree (especially with grapes and watermelon). However, this system would likely require considerable investment and infrastructure (for refrigeration, for example), and would be complicated by the large number of individuals growing these on household plots rather than collective farms.

Another solution (a favourite of the lead author) would be to increase substantially the number of mulberry trees growing on edges of agricultural fields to reduce waterlogging and salinity problems. These are also used to grow silk worms. Unfortunately, we have not been able to access enough data to support our claim, but we believe there is an untapped potential in silk production. In 2004, we have been able to buy silk fabric in 'plain' colours from a local factory for about $5/m (which was considerably more expensive than the traditional colourful designs which sold at $1.5 to $2/m). With its rich history and central location in the Silk Road, Uzbekistan could find an interesting angle to market its silk fabrics on the world market.

12.4 Large-scale irrigation projects are theoretically beneficial

However there are examples of outstanding failures which partly led to ecological catastrophes. We think that irrigation per se does not necessarily lead to land degradation. Even in the famous case of the Mesopotamian plains, the idea that ancient Sumerian irrigation caused irreversible salinization (Jacobsen and Adams, 1958) is far less evident than often assumed in the public discussion (Powell, 1985).

However, some irrigation projects in arid lands ended disastrously. One of the best-known examples is the former Aral Sea (Nikolski, 1996). Irrigated agriculture in the vicinity of the lake basin was applied for many centuries. It was practiced mainly in the areas with rich soils, with a deep water table or with fresh groundwater where the irrigation requirements were minimal. The major part of the irrigated lands was located in river valleys, in deltas, and in foothills close to the mountains. The irrigated plots were small and widely separated from each other. Therefore natural drainage served well enough; artificial drainage, in form of ditches, had been rarely used. The principle irrigated crops were cereals and alfalfa. They occupied more than half of total irrigated area in the Aral Sea basin. Cotton occupied less than 20-30% and rice no more than 5-15% of irrigated area, depending on the years.

During the twentieth century, the population of the Aral Sea basin doubled, and irrigation was intensively developed, leading to almost a tripling of the irrigated area. The basic source of irrigation water is two large rivers, the Amu-Darya and Syr-Darya. Large irrigation systems covering hundred thousands of hectares were built mainly in the steppe and desert parts of the Aral Sea basin, far from the river beds, where the groundwater table was very deep (more than 30-50 m).

Cotton became a main crop, following the government's decision to increase raw cotton production. That led to increased irrigation requirements and to increasing use of mineral fertilizers, pesticides and defoliants (Aydarov et al 1992). In addition, the area of rice cultivation increased significantly.

The estimated average efficiency on the irrigation systems was very low and did not change appreciably over time. Irrigation was mainly developed by construction of new irrigation systems and less by reconstruction of old ones. About 50% of the irrigation water taken from the rivers was lost because of seepage from canals and deep moisture leaching in the irrigated fields. Even waterlogging took place and the groundwater table sometimes rose to a depth of less than 1.5 m. Due to large amounts of soluble salts in the deep layers of the soils, and as a result of the disturbance of the natural groundwater balance, the worst possible case materialised: saline groundwater rose to the surface. Later analysis of experimental data showed that the only way to save water and at the same time to prevent soil salinity is to keep the water table at the maximum possible depth (not less than 2.5-3 m), and use only water of good quality.

The growing irrigated area and inefficient water use made drainage construction and management of the huge amounts of agricultural wastewater a necessity. Formerly it was supposed that drainage would not only prevent soil salinity and waterlogging, but would desalinate groundwater as well. Then fresh groundwater could have been used for sub-irrigation. Additionally, it was supposed that the repeated use of drainage waters mixed with river waters would increase the effective use of limited water resources. However, it turned out that the salt concentration of drainage waters did not change much. In contrast, it appears that huge amounts of dissolved soil salts, pesticides, and nutrients were injected into the geological water circulation (Nikolskii, 1996). This contaminated water was used not only for irrigation, but also for human consumption. Therefore the number of severe diseases among the population grew considerably, while the rise of saline groundwater under irrigation systems required increasing amounts of irrigation to prevent soil salinity – despite the newly constructed drainage.

12.5 Possible solutions - more water

At first, it seemed possible that this problematic situation could be solved with more water, transferring a certain amount of fresh water to the Aral Sea basin. A transfer system was designed: a channel more than 2,000 km long, 12 m deep and 120 m wide should carry Siberian water from the river Ob. But after further analysis, it became clear that the additional water would only make the situation worse, if the present technology of water management remained. About 50% of the existing water resources in the Aral Sea basin were not used, but lost to the seepage in the canals and fields. These losses caused the groundwater table to rise and created drainage water outflows contaminated with toxic agricultural residues and soil salts. Part of the saline drainage water was channelled into closed basins in the desert and evaporates there. This created artificial lakes with a high concentration of pesticides.

To summarise, the results of the Soviet irrigation project in the Aral Sea basin were devastating. The rivers dried up since their flow was entirely used for irrigation.

The contamination of irrigated soil and water increased downriver, was severe in the middle parts and most severe in the lowest parts. The level of pesticides in domestic animal meat exceeded the permissible level by 8 times, and in the vegetables by 16 times. The number of serious diseases, such as viral hepatitis, typhoid fever, cancer of the esophagus, increased by 5-30 times. The coastal population at the former Aral Sea lost their jobs, and the endemic flora and fauna in the littoral zone of the former coastal zone disappeared.

The annual flooding of the plains does not occur any more, causing strong degradation of formerly rich alluvial soils. Numerous smaller fresh water lakes (some of them used for fishing) dried up. Instead, toxic lakes appeared. Natural pastures for domestic and wild animals disappeared. The amplitude of annual air temperature oscillation has risen by 2-3 ^{o}C up to a distance of 100 km from the lake. The Aral Sea itself has fallen more than 16 m, and is divided into two parts. A dried salty surface appeared on the former lake bottom, covering an area of more than 40,000 km^2 with a salt content of about 100-300 tons/ha in the upper 1 m. About 65 million tons of salty dust are annually blown away from the former lake bottom and carried by the wind for more than 300 km. About 1 ton of salts fall annually on each hectare of the former rivers' deltas. Salty dust clouds rise very high and even reach the mountain glaciers, accelerating their melting. Salty rains with a salt concentration up to 160 mg/l occur in the Aral Sea region. The salt concentration of the lake rose gradually after 1960 and reached 30 g/l at the end of 1980s. According to forecasts, water salinity will increase up to 80-85 g/l even if it is possible to increase the rivers' inflow to 20 km^3/year (Razakov, 1990).

Reasons for the ecological catastrophe at Aral Sea include:

- The excessive growth of the irrigated area.
- Inefficient water use.
- Population growth.
- Poor sanitary conditions.

These conditions exist today in most semi-arid and arid areas. If no suitable planning procedures are used, there is a high risk that in the course of the implementation of progressive development large-scale irrigation projects will result in further environmental catastrophes.

12.6 Conditions of irrigated lands in Karakalpakstan

Lower reaches of Amu Darya River occupies vast territory, covering whole lands of Khorezm area and Karakalpakstan Republics, as well as Tashkhauz area of Turkmenistan. The area of modern delta of Amu-Darya River, including Usturt Plateau and the Aral Sea, is nearly 14 million hectares.

Drying up of the Aral Sea and development of irrigation in upper parts of Amu-Darya River basin, as well as regulation of river flow substantially have affected on hydro-geological and melioration condition of irrigated lands of the region. As a result of water flow reduction from Amu-Darya began the intensive process of desertification both in a zone of drained bottom of the Aral Sea and in delta of the river. Under existing conditions in lower Amu-Darya the situation with water recourses remains tense and unstable.

Contemporary task is to increase yields of agricultural products by vital melioration of irrigated soils. This have caused the necessity of detailed studying of hydro-geological and melioration conditions of the territory lands. Melioration object in lower Amu Darya is quarter complex of bedrocks in which subsoil waters are formed. Therefore the main attention is given to the characteristics of upper water-bearing stratum.

The land of Karakalpakstan is represented by fourth period sedimentary rocks of alluvial origin with the depth from 10 to 35 m. Three ground (soil) complexes, which are sharply distinguished by structure, are allocated in this area. The first complex is river-bed sediment, which is mainly fine granular sand covered by over layered sandy loam and loamy soil. The depth of this complex is between 1.50-1.95 m, and filtration coefficient is between 1.28-1.42 m/day.

The second complex is river-bed sediment of stray channels and temporal lakes. They might be one, two or three layer. Water-bearing complex consist thin

Figure 12.1. The Aral Sea. Satellite images show changing waterlevels in the Aral Sea1989 (left) and 2014 (right). Photo: NASA.

and fine granular sand with the filtration coefficient between 5.2-7.5 m/day. This complex is covered by small-grained ground with the depth from 4.5 to 11.6 m. The water permeability of this ground is lower than in the area of river-bed sediments, and its filtration coefficient changes from 0.38 up to 0.96 m/day.

The third complex is submitted by lake sediment. Open-pit mine of this complex is combined by clay within which layers of sandy loam, rarely with layers of sand. The depth of this complex changes from 3.5 up to 12.5 m, and filtration coefficient from 0.15 to 0.83 m/day.

12.7 Salinity

For realization of hydro-geologic and melioration measures, as well as for definition of soil saltiness we have investigated land saltiness of seven regions of Karakalpakstan, which are: Amu-Darya region, Nukus region, Kegeyli region, Chimbay region, Karauzyak region, Takhnakupir and Muynak regions. For this experiment selection of soil samples was made on the area of 219 thousand hectares of irrigated land. On 20% of samples were made complete cycle of analyses with definition of toxic salts in soil. Results of experiment are given in Table 12.1.

On the basis of chemical analyses by using water extraction method we have determined the types and degrees of saltiness of soil grounds. Type of the soil salts

Table 12.1. Salinity of the irrigated ground of seven regions of Karakalpakstan, (thousand hectares).

Regions	Whole irrigat-ed land	Not salted lands	Faintly salted	Medium salted	Heavily salted
Amu-Darya	38667	8948	9214	15486	5019
Nukus	26869	4624	8280	9762	4203
Kegeyli	39070	8180	10934	15310	4646
Chimbay	46709	9733	18481	12322	6173
Karauzyak	33689	8034	10434	10413	4808
Takhtakupir	33851	6956	13803	9913	3179
Muynak	540	14	119	192	215
Total	219395	46489	71265	73398	28243

Table 12.2. Dynamics of the change of whole irrigated land of Karakalpakstan within 2000-2012 on the degree of ground soil saltiness (Thousand Hectares)

years	Whole irrigated land	Not salted lands	Faintly salted	Medium salted	Heavily salted
2000	500,09	49,52	244,10	158,55	47,92
2001	500,16	49,96	215,74	172,15	62,31
2002	500,20	73,80	169,73	192,22	64,45
2003	500,16	79,34	178,81	182,76	59,25
2004	500,10	92,99	180,81	169,94	56,36
2005	500,12	103,17	169,02	171,36	56,57
2006	500,40	105,13	158,45	175,86	60,96
2007	504,00	107,07	154,79	182,73	59,41
2008	504,53	106,19	157,23	183,97	57,14
2009	515,05	112,46	164,26	185,07	53,26
2010	515,29	113,30	154,03	196,63	51,33
2011	515,22	116,94	148,77	200,45	49,06
2012	515,22	119,25	150,17	198,85	46,93

of the investigated seven regions are mainly chloride-sulphate, rarely chloride, sulphate-chloride or sulphate. The saltiness degree of the ground was determined as the sum of all toxic salts. The previous such salt sampling in these areas was carried out in September - October of 2008. At comparison of results of present testing with previous there are following changes: the area of not salted lands are increased to 3.63 thousand hectares, the area of faintly salted irrigated lands are decreased to 5.29 thousand hectares, the area of middle salted lands is increased to 3.74 thousand hectares, heavily salted are decreased to 2.28 thousand hectares.

Dynamical analysis of whole irrigated land of the Karakalpakstan within 2000-2012 on the degree of salinity of the ground soil show us that the level of soil salinity still remains tense and unstable (see Table 12.2). During these years the whole irrigated land area increased to 15 thousand hectare, or to 2.9%, not salted lands area increased to 70 thousand hectare, faintly salted lands area decreased to 94 thousand hectare, middle salted lands area increased to 40 thousand hectares, and the area of heavily salted lands are remains almost the same. Thus, in 2012 almost 77% of all irrigated land of Karakalpakstan were salted, and only 23% were not salted lands. From this we may to conclude that existing hydro-geologic and melioration conditions on a significant part of irrigated lands of Karakalpakstan is characterized as unsatisfactory. And such situation is connected not only with high level of underground waters, which influence to intensive evaporation, but also with high mineralization of underground and irrigation waters, which causes to the raising of salts to surface of the ground.

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UZWATER

This compendium is produced for a master level course in the UZWATER project. It consists of some newly written material as well as previously published texts extracted from freely available books, reports and textbooks on the Internet, dominated by publications from the Baltic University Programme. The sources used for each chapter is listed at the end of the chapter. The compendia of the Uzwater project are produced exclusively for Master students free of charge at the participating Universities and is not to be sold or be freely available on the Internet.

The UZWATER project is an EU TEMPUS project. It includes 8 universities in Uzbekistan and deals with university education for sustainable water managment in Uzbekistan. Uppsala University and Baltic University Programme is one of the six EU partners in the project. Lead partner is Kaunas University of Technology.

The main objective of the project is to introduce a Master level study program in environmental science and sustainable development with focus on water management at the eight partner universities in Uzbekistan. The curriculum of the Master Programme includes Environmental Science, Sustainable Development and Water Management.

The Sustainable Development unit will include the basic methods used in Sustainability Science, in particular introduce systems thinking and systems analysis, resource flows and resource management and a series of practical tools for good resource management, such as recycling, and energy efficiency.

The specific objectives of the project are:

- to establish study centers at the partner universities in Uzbekistan
- to improve the capacity to train master students with expertise to address the severe environmental and water management problems of the country;
- to support the introduction and use in Uzbekistan of modern education methods, study materials, and e-learning tools;
- to encourage international cooperation at the partner universities;
- to strengthen capacities to provide guidance to authorities and the Uzbekistan society at large;
- to ensure the visibility and promotion of the Master Programme through web pages, printed material and cooperation with society;
- to ensure continuity of the Master Programme and long-term support of the project outcomes at partner universities beyond Tempus funding.

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