An integral method for assessing the impact of dredging on the ecological state of river water resources

M A Buchelnikov¹, Yu I Bik¹, V N Kofeeva¹, I G Bereza²

¹ Department of Construction Production, Structures and Protection of Water Resources, Siberian State University of Water Transport, 33, Shchetinkina St., Novosibirsk, 630099, Russia
² Ushakov Maritime State University, 93, Lenin Ave., Novorossiysk, 353924, Russian Federation

E-mail: v.n.kofeeva@nsawt.ru

Abstract. The study is aimed at solving the urgent problem of the impact of dredging operations carried out in river channels on the hydroecological state of river sections as the most important water resource. Many different factors arising from man-made interventions radically change the hydrology and hydroecology of rift areas. Taking into account all kinds of changes during the design phase leads to both the creation of sustainable tracks and the minimum impact on the environment. The aim of the study is to develop an integral quantitative method for assessing dredging and channeling works on the hydroecological state of river sections. The proposed method is based on the formalization of influencing factors and an algorithm for their quantitative assessment. It has a number of properties that distinguish it from the calculations previously used for hydroecological assessment, describing the interaction of the channel, flow and technogenic systems, in particular, the ability to obtain integral quantitative data. The classification of factors is proposed: by the degree of the direction of impact, the size of the area of influence, by the time duration. The possibility of using this method to create artificial neural networks for the design of dredging is shown. The possibility of functioning of an artificial neural network of the perceptron type, consisting of several layers of neurons, has been demonstrated.

1. Introduction

One of the main ways to create efficient shipping lanes on inland waterways is channel dredging. Dredging is associated with the movement of large volumes of river alluvium and, together with the accompanying engineering measures for channeling, significantly changes the hydrological and hydroecological conditions of the river sections.

Unsuccessful dredging leads to an increase in the repetition of work or to such changes in the river section that were not planned or that lead to undesirable consequences that further worsen the navigation conditions, flow hydraulics, create hazardous phenomena or destroy river and coastal ecosystems. In this regard, the problem of correct assessment of changes occurring in the river section as a result of engineering works is very urgent.

The currently used methods for calculating changes in hydrological and hydroecological conditions make it possible to evaluate many parameters: to calculate the effect on the hydraulics of a river flow, to determine the balance of drifts, to assess the stability of the track and the negative impact on the
environment. For all their necessity, the methods used have two significant drawbacks. The first is the lack of integrity, i.e. quantitative criteria for those changes that will occur in each specific place of the drift area. The second is the relative complexity of their application to create adequate mathematical models and use in artificial neural networks.

Artificial neural networks (hereinafter referred to as ANN) are algorithms of a certain type, created on the likeness of the principles of functioning of biological structures of nerve cells. ANNs are a single complex of interacting simplest processors that receive incoming signals and send outgoing signals to other neurons. At present, very complex practical tasks are performed with the help of ANN, namely:

- design and construction of all kinds of objects;
- recognition of images, text, environment;
- process control;
- forecasting and analysis in various fields.

It is obvious that the creation and tuning-up of ANNs should be based on specific algorithms. The creation of an ANN consists of choosing its type, building a network architecture, determining analytical conditions and mathematical functions of neurons. The ANN tuning-up process is called "learning". The training consists in determining the correct coefficients of connections (weights) between the processors until the moment when the ANN begins to correspond to the task set before it and to produce adequate results. Creation of ANNs designed to improve the efficiency of engineering works in the riverbed can be considered as a promising avenue.

In connection with the above, the purpose of the studies was to develop a method for a quantitative integral assessment of changes in hydrological and hydroecological conditions of a river section, applicable for use in ANN. To achieve the goal, the following tasks were solved: heterogeneous influencing factors were formalized, an algorithm for obtaining a quantitative assessment of changes was drawn up, and the mechanism of operation of this algorithm in simple ANNs was shown.

2. Materials and methods

The essence of the developed method consists in the classification and formalization of the impact of man-made factors arising as a result of dredging and channeling operations.

The initial materials are channel surveys of rift areas with projected tracks and channeling structures and data on changes in flow and channel parameters.

To consider the possibilities of using the method in ANN, one of their most common types - the perceptron - was chosen. This type consists of three types of elements (neurons), namely: input neurons (those that receive a signal), hidden or associative neurons (determining conditions), output neurons (those on which the decision is formed). The essence of the developed method consists in the classification and formalization of the impact of man-made factors arising as a result of dredging and channeling operations.

3. Survey of literature

For many years, a team of employees of the Novosibirsk State Academy of Water Transport (now the Siberian State University of Water Transport) has been studying the impact of technogenic impact on the hydrology and hydroecology of water bodies and watercourses. In particular, in recent years, a method has been developed that makes it possible to assess the ongoing dredging operations both from the transport and from the hydroecological sides [15, 16]. An overall assessment was given of transit dredging as a hydrological factor [17]. Approaches to substantiating dredging volumes and increasing the safety of the navigable route were reflected in the works of Professor V. A. Sedykh [22, 23]. A number of methods for a comprehensive assessment of anthropogenic impact are presented in a monograph devoted to the hydrology of small water bodies [15].

Theoretical and applied research devoted to the complex processes of interaction of a river channel, stream and technogenic systems belong to the staff of N. I. Makkaveev Research Laboratory of Soil Erosion and Channel Processes, Faculty of Geography, M. V. Lomonosov Moscow State University,
under the guidance of Doctor of Geography, Professor R. S. Chalov. The works of this research team have laid a solid scientific basis for the design of sustainable shipping routes, taking into account all the features of channel morphology [14, 21, 24–27].

Over the past few years, foreign authors have published a number of articles aimed directly at the problem of the impact of operations in river channels on the hydrology and hydroecology of water systems.

Various methods of assessing the technogenic impact on the flow and channel have been considered by a number of researchers from China, the United States and other countries in which rivers are used as transport routes.

H. Cai, H. Savenije and others [3] model the influence of river discharge and dredging operations on the spread of tidal waves in the Modaomen Estuary (China). Dredging in the estuary has had a tangible impact on the spread of tides. The paper includes an assessment of the impact of these human interventions through the use of a new analytical (hydraulic) model that calculates tide spread and damping as a function of depth and river discharge.

The works of G. Cook and A. Int [4] are devoted to the description of a pilot dredging project on the small river Wekiva in Florida.

The topic of the influence of nonmetallic building materials quarries on the ecology of water bodies is relevant for such countries as USA, Great Britain, Australia, and Japan. It is reflected in the studies by J. Freedman and J. Stauffer [5].

R. Frings, B. Berbee, G. Erkens established that large-scale operations on the Waal River (Netherlands) led to a change in the morphology of the channel [6].

F. Gob, G. Houbrechts, J. Hiver and F. Petit [7] studied the consequences of dredging in the Ardennes rivers (in particular, the Semois, the channel of which is characterized by large meanders, narrow floodplain and pebble bars), which is usually carried out in small volumes. The extraction of soil here is intended to prevent flooding, the amount of gravel removed from the channel is small. The dredging resulted in a stable track several kilometers long and about 2 m deep, which functioned as a sediment settler (which in turn should discourage flooding). In order to investigate the efficiency of this settler, mathematical modeling methods based on the transport equations of Meyer-Peter and Müller were applied, and then the simulation results were compared with empirical data; the total values diverged, i.e. the proposed model could not adequately describe the situation.

The intensification of the use of water resources is also taking place on the Korean Peninsula. J Lee, S. Lee, S. Bai (S. Wu) and D. Shin [9] proposed a hydrological “framework model” for the calculation and maintenance of river dams, the general development of river areas, and the calculation of the consequences of dredging on rivers. The model is interesting in that it takes into account both hydrological parameters and economic costs.

In recent years, ANNs have found application in many theoretical and applied studies, including scientific research in the field of water transport, in particular for modeling the operation of port equipment, dead reckoning, solving applied mathematical problems [18–20].

A number of researchers use ANNs to simulate hydrological processes of natural watercourses [1, 2, 9, 11–13]. Thus, models of a number of rivers have been developed, models for forecasting runoff have been developed, and principles of learning ANNs by the feedback method have been developed.

4. Results and discussion

The first stage in the development of the method was the classification of as many influencing factors as possible, factors, that arise during dredging and channeling operations. In our opinion, the following classifications can be proposed:

1. By the degree of direction of impact.
2. By the size of the area of impact.
3. By time duration.

Let's consider all the classifications in order. Dredging and channeling operations can lead to both negative (unwanted) and positive (desirable) impacts. For example, erosion of the coast, an increase in
the likelihood of jamming, destruction of natural biotopes, etc. will be attributed to negative impacts, and the increase in the stability of tracks, prevention of erosion of banks - to positive ones.

In terms of the scale of the changes caused, factors can be:
1. Local (local changes in hydrological conditions), those that occur in the immediate vicinity of hydrosystems, the operation of mechanisms, dumps, etc.
2. Regional (within the region, a series of rifts, a group of islands, a river section).
3. "Global" (in our case, affecting an extended section of the river of several hundred kilometers).

By the time of exposure, it is worth highlighting:
1. Short-term factors, i.e. those that have an impact only directly during works.
2. Factors acting during the navigation period (up to 1 year).
3. Factors with an effect over the years.

We formalize the negative and positive factors of influence, dividing them by territorial and temporal extent. Let the letter indices denote the following.

By the direction of impact:
P - factors are positive, favorable.
N - factors are negative, adverse.

By territorial length (coverage scale):
L - local
R - regional
G - "global".

By impact time:
A - short-term factors, i.e. those that have an impact only directly during works.
B - factors acting during the navigation period (up to 1 year)
C - factors with an effect over the years.

To move on to a more accurate quantitative assessment of changes in the ecological situation, we take the above list of factors and assign each of them its own index (see Table 1), negative factors will have indices N1 - Nn, and positive factors P1 - Pn.

| No. | Factor                                           | Negative or positive | Length | Impact duration | Impact coefficient (for factors A/B/C respectively) |
|-----|--------------------------------------------------|----------------------|--------|-----------------|-----------------------------------------------------|
| 1   | The appearance of spots (plumes) of turbidity    | N                    | L      | A               | 0.5                                                 |
| 2   | Destruction of the biotope in the dump area      | N                    | L      | A, B            | 0.0 / 0.4                                           |
| 3   | Destruction of the biotope in the track area     | N                    | L      | A, B            | 0.0 / 0.4                                           |
| 4   | Unfavorable change in the flow filaments pattern | N                    | L, R   | A, B, C         | 0.8 /0.8/0.8                                       |
| 5   | Change of the speed mode of the river            | N                    | G      | C               | 0.9                                                 |
| 6   | Decrease of low-water levels at equal water flow rates | N          | R, G   | C               | 0.9                                                 |
| 7   | Shallowing of traditional migration routes       | N                    | G      | C               | 0.9                                                 |
| 8   | Accidental contamination of water by oily bilge waters, lubrication of moving parts, household waters and debris | N | L | A | 0.9 |
| 9   | Desirable changes in the direction of the flow filaments | P | L, R | B, C | 1.5/2.0 |
| 10  | Creation of changes in the bottom relief that are positive for biota | P | L, R | C | 2.0 |
| 11  | Improving water exchange between the river reach hollows | P | R, G | C | 1.2 |
| 12  | Removal of contaminated soil from the channel    | P                    | L, R   | C               | 1.5                                                 |
Thus, for example, the factor "Occurrence of spots (plumes) of turbidity" will have an index of 1NLA, and the factor "Desirable directions of change of flow filaments" - 9PRC The list of factors given in Table 1 is not exhaustive, when establishing new ones it will be enough just to classify and assign indices to them.

Of particular difficulty is the correct determination of the impact force (expressed as the impact coefficient) of one factor or another, which depends both on its physical properties and on the hydrological situation. In our opinion, the impact factors should be determined by experts. Having considered the entire set of factors acting in the given area, we determine the areas of their impact. In order to obtain a quantitative result, such zones should be designated discretely, in the form of a set of “sub-areas” or “cells”. The size of the cells is determined depending on the required accuracy of the results; the optimal sizes are 100 m × 100 m or more. In each cell, we designate the acting factors.

The initial “picture” will be a survey of the rift area prior to dredging (see Figure 1). A grid of cells is superimposed on it (of course, so far without factor indices) and, in the simplest case, the initial productivity in each of the cells is taken as 1, all single values are summed up. The sum of single values (n0) in the initial situation will be denoted as N0, it will reflect the initial bioecological picture of the area.

However, it is possible to estimate the picture more accurately if for each cell the differentiation of the cells by their significance is made. In this case, the cells corresponding to those sites that have the least impact on the hydrology of the area will have a value of 1, the average impact - 2, and the most important - 3 (see Figure 3), for better visualization they can be marked with different colors.

![Figure 1. Survey of a rift area with a superimposed grid of cells.](image1)

![Figure 2. Survey of the rift area with a superimposed grid of cells and indicated factor indices at ni0 = 1.](image2)
Figure 3. Survey of the rift area with a superimposed grid of cells and spaced factor indices for \( n_i0 \), depending on the degree of influence of a cell.

On the existing survey, all the necessary tracks and structures (dams, groins, spur dikes, spurs, etc.) are designed, the places of the dumps are indicated. Using standard methods, we calculate the change in flow rates, the size of turbidity plumes, the area of dumps, tracks, changes in depths, etc.

In each cell, which was affected by this or that impact, we enter the indices of the factors. Even after this simple operation, we already get the first numerical value characterizing the hydrological impact on the site - the number of cells affected by the impact factors (\( N_f \)). It is possible that already at the first stage it is possible to try to change the plan of works in such a way that \( N_f \) becomes less (or optimal); i.e. to make a preliminary comparison of two or more options and give them a rough, preliminary estimate.

It seems necessary to divide the impact pattern in terms of time, i.e. to represent it as it will be during the production of works, at the end of the navigation period (less than 1 year) and in the long term (1 year or more). To do this, the cells affected by factors with indices A, B and C are represented each in its figure (see figure 4).

Figure 4. Survey of the rift area with a superimposed grid of cells and separation of factors with different time effects (a - short-term, c - medium-term, c - long-term).

After such a division, quantitative information will be added. It will already be possible to say how much this or that scheme of works in the channel will turn out to be unsafe or ineffective in the short, medium and long run.
Then we turn to more accurate, numerical estimates of the environmental impact on the river section. Actually, there is no need for cartographic information at this stage: after splitting into cells, the data is converted into the form of a numerical matrix (data array) (see Figure 5) and the calculation of the impact is performed both for each cell, and then for the entire area as a whole.

Let’s consider examples of calculation for one separate cell.

For example, two factors act in a cell: 2NLA - sedimentation of soil particles from spots (plumes) of turbidity and 11NLA - shallowing of a river section. The impact factor for the first factor is 0.7, for the second one - 0.9. Therefore, with the initial cell value \( n_{i0} = 1 \), its new value is \( 1 \times 0.7 \times 0.9 = 0.63 \). If \( n_{i0} \) depends on the significance of the cell, then for \( n_{i0} = 1 \) the value after impact will naturally be also equal 0.63, for \( n_{i0} = 2 \) - \( 2 \times 0.7 \times 0.9 = 1.26 \), with \( n_{i0} = 3 \) - \( 3 \times 0.7 \times 0.9 = 1.89 \).

![Figure 5](image_url)

We make a calculation for the entire area as a whole. The initial value of each cell was designated by us as \( n_{i0} \), the new values are designated as \( n_{i1a} \, n_{i1b} \, n_{i1c} \) for factors with indices A, B and C, respectively. Then the value for the entire area under the influence of short-term factors will be:

\[
N_{ia} = \Sigma n_{i1a}
\]

For mid-term and long-term, respectively:

\[
N_{ib} = \Sigma n_{i1b}
\]

\[
N_{ic} = \Sigma n_{i1c}
\]

To assess impact we find the differences:

\[
\Delta N_{a} = N_{0} - N_{ia}
\]

\[
\Delta N_{b} = N_{0} - N_{ib}
\]

\[
\Delta N_{c} = N_{0} - N_{ic}
\]

The more is \( \Delta N \), the more significant the impact of the works carried out. We can add another relative indicator of the change in \( N_{k} \) (for short-term, medium-term and long-term factors, respectively, \( N_{ka} \), \( N_{kb} \), \( N_{kc} \)), expressed in percent:

\[
N_{k} = \left( \frac{(\Delta N - N_{0})}{N_{0}} \right) \times 100
\]

If \( \Delta N \) has a negative value, therefore, the totality of works has led to a deterioration in the hydrological situation in this area. Expressing this in terms of \( N_{k} \), the following gradation can be
proposed:
Nk = 99-90% - weak negative impact (the site remains practically the same plan).
Nk = 90-70% - moderate negative impact.
Nk less than 70% - strong negative impact (most biotopes are damaged).
If ΔN> 0, then the work has led to the desired impact. The Nk gradation here can be as follows:
Nk = 101-110% - weak positive impact (the site remains practically the same).
Nk = 110-130% - moderate positive impact.
Nk above 130% - a strong positive impact (the task of the work has been solved).
The second, more complex option, in which the significance of each cell is designated 1, 2 or 3
does not differ from the first in the calculation algorithm.
Having developed the calculation algorithm, let's move on to the issue of its application in ANN.
As mentioned earlier, we will choose a fairly simple perceptron with 1-3 layers of associative neurons
as the most suitable type of ANN. The quantitative values of technogenic factors will serve as
"signals" arriving at the input neurons. Associative neurons should contain functional dependencies
of the hydrological conditions of each small area-cell. The factors influencing factors will be used as
weights.
For clarity of ANN functioning, we will compose the simplest network consisting of only two
layers: a layer of input signals and one "decisive" neuron (see Figure 6).
As input signals, let us define such parameters as “sediment accumulations of the track”, “presence
of rocks” and “presence of feeding grounds for juveniles”. Thus, the primary conditions will be:
X1 - whether there are rocks in this place;
X2 - is the cell located in the feeding area of juveniles;
X3 - whether the track will be stable here.
The function of a decision neuron can be represented as:
\[
f(x) = \begin{cases} 
1 & x \geq 0.5 \\
0 & x < 0.5 
\end{cases}
\] (8)
We set the following weight coefficients: W1 = 0.5; W2 = 0.5; W3 = - 0.5.

![Figure 6. Scheme of the simplest ANN.](image)

If there are rocks and the presence of feeding grounds for juveniles (factors are undesirable, but not
critical) in this cell, then the decisive neuron will give a value greater than 0.5, therefore, the answer
about the possibility of passing the track through this place will be positive. However, if the track is
unstable, the value will become less than 0.5 and the network will automatically "prohibit" the
presence of the track.
ANN training will consist in the selection of the significance of the influence of factors on certain hydrological or hydrobiological conditions, and the final result will be the “decision” of the output neuron about the presence or absence of a negative impact in each “cell” of the considered rift area. When the network is large enough, it is possible to train on the existing rift areas with tracks, which have shown their stability over many years.

After the simplest network, making a decision with one "cell", has been "tuned-up", the network architecture can be made more complicated (see Figure 7). The result obtained on the decisive neurons of the primary link will serve as an input signal for the network, giving the result on the entire rift area. If the works in one area affects the neighboring one, then the structure of the network can cover a longer section of the river, establishing, among other things, feedbacks.

![Figure 7. The principle of complicating the architecture of the ANN.](image)

5. Conclusion
The presented method has a number of properties that distinguish it from the "classical" calculations describing the interaction of the channel, flow and technogenic systems, in particular, the ability to obtain integral quantitative data. However, the values showing the change in one or another factor in the corresponding "cell" cannot be obtained without the use of generally accepted methods.

The applicability of the method for constructing an ANN based on it is demonstrated by the example of the operation of the simplest perceptron, which consists of two layers of neurons. Of course, a working ANN should consist of 4-5 layers and contain all the required conditions.

In our opinion, the prospects for using ANN in the industry are very broad and can cover a number of areas, primarily those related to increasing the efficiency of track operations, namely:

1. Modeling and forecasting of hydrodynamic and channel processes in natural conditions and under anthropogenic impact.
2. Automation of the design of dredging tracks, bank protection and channeling structures.
3. Assessment of the environmental impact of track work on aquatic ecosystems.

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