Previous experience and prospects of using certain quantitative methods for the environmental assessment of hydraulic engineering constructions during the design process

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LLC "Eco-Express-Service"

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Locations of Russian port complexes designed with the participation of LLC "Eco-Express-Service"
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Port construction development in Eastern Gulf of Finland

Dynamics of freight turnover of Russian ports in Baltic Sea according to Seaport Administration data, million tons

Years

<table>
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<tbody>
<tr>
<td>Vyborg</td>
<td>143.7</td>
<td>141.1</td>
<td>163.4</td>
<td>172.3</td>
<td>194.5</td>
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<tr>
<td>Vysotsk</td>
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<td>Ust-Luga</td>
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<td>Primorsk</td>
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<td>Total EGof</td>
<td></td>
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Dynamics of water pollution index in the Neva Bay (2000-2014)

Average annual yield of fisheries in the Neva Bay (tons) (1972-2012)

Dynamics of new territories’ formation: cumulative total area ($S_\Sigma$, ha) and dredging volume (V, million tons per year) in Eastern Gulf of Finland.

\[
\ln S_\Sigma = 7.0 - 0.05t_{2000-2012}, \quad \ln V = 7.0 - 0.05t_{2000-2012}
\]
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The structure of environmental costs (%%) in case of port complexes construction and exploitation

Average data of STP (sea trade port) Ust-Luga terminals

- **Construction period**
  - Emission: ~0%
  - Sediment pollution and contamination: 8%
  - Waste water discharge: 2%
  - Waste products: 4%
  - Terrestrial vegetation: 32%
  - Terrestrial fauna: 54%

- **Exploitation period**
  - Emissions: 1.0%
  - Wastewaters: 20.5%
  - Waste products: 5.5%
  - Aquatic bioresources: 73.0%

**Average damage caused to aquatic bioresources of 195 projects total environmental costs**

- **Ratio of sediment pollution and contamination payments and damage to aquatic bioresources**
  - $y = 0.3814x + 40122$
  - $R = 0.69$
Possible multicriteria measures
(ranged according to complexity degree and entirety)

1) The resulting and average weighted expert-rating scores (including or excluding a criteria of "weight coefficients").

2) Analogues of saprobity coefficients – similar to the structure of Pantle-Buck (Pantle, Buck, 1955), Sládeček (Sládeček, 1965) and Rotschein-Toderash (Rotschein-Toderash: Toderash, 1984) indexes: taking into account indicator values of characteristics, its "indicator weights" and measures of kurtosis.

3) The isobolic method of the multifactor impact expected levels of compared alternatives on environment components evaluation.

4) Classification multivariable techniques:
   ● Direct comparison of Euclidean distances (or other measures of multivariable distances) in criteria hyperspace normalized with a uniform criteria trend (0 – optimum (natural or minimum transformed background) state, 1 – pessimal state):
     – expected distances between background and impact coordinates of compared alternatives in criteria hyperspace;
     – expected distances between impact coordinates of compared alternatives in criteria hyperspace.
   ● Cluster analysis of results.
Criteria (total amount – 390) are divided into 5 criterion groups:

**Criterion group 1.** Criteria involving technical and technological differences of the routing options.

- fault risk;
- sandbanks;
- underwater ferromanganese concretions;
- ice scouring;
- underwater obstacles;
- erosion by sea bottom currents;
- hillslope processes;
- navigation (routes, anchorages, traffic);
- dangerous navigation zone;
- military zones;
- cables and pipelines to be crossed;
- industrial fishing areas to be crossed;
- land transport routes.

**Criterion group 2.** Criteria involving restrictions of natural resources management for each of the routing options.

- sandbanks;
- underwater ferromanganese concretions;
- ice scouring;
- underwater obstacles;
- erosion by sea bottom currents;
- hillslope processes;
- navigation (routes, anchorages, traffic);
- dangerous navigation zone;
- military zones;
- cables and pipelines to be crossed;
- industrial fishing areas to be crossed;
- land transport routes.

**Criterion group 3.** Criteria involving the initial condition of the environment.

- sea bottom soils;
- dangerous exogenous geological processes;
- marine environmental quality indicators;
- characteristics of major hydrobiont communities.

**Criterion group 4.** Criteria involving impact on the environment.

- impact on landscapes and soils;
- impact on atmosphere;
- noise impact;
- impact on abiotic aquatic environment;
- damage to water bioresources;
- impact on terrestrial biota;
- damage to avifauna of offshore sections;
- impact on marine mammals;
- impact of wastes on the environment.

**Criterion group 5.** Assessment of impact under accidents.

- accidents during land sections construction;
- accidental oil spill on water area during construction;
- impact on atmosphere at water area accidents;
- accidents at operation stage.
Four competitive methods were used in order to combine the results obtained into an overall comparative score:

**Method 1.** Scoring which does not involve weighting factors for the criteria, or the ratio factor for offshore/onshore sections of the route (if a routing option displays an advantage by any criterion, this scores one point for that routing option).

**Method 2.** Scoring which does involve weighting factors for all the criteria but not the ratio factor for offshore/onshore sections of the route (this method is different in that various criteria are assigned different indicator roles, expressed by the corresponding weighting factor (W) – from 1 meaning a minimum to 5 - a maximum).

**Method 3.** Scoring which does not involve weighting factors for the criteria but does involve the ratio factor for offshore/onshore sections of the route.

- As with Method 1, the indicator role of every criteria is taken to be equal. However, this method also involves the ratio of the offshore section to its onshore section length.
- A correction factor (L1), equal to the offshore section length as percentage of the total length of the Russian sector, is used for the criteria describing the offshore section of the route.
- A correction factor (L2 = 1-L1), equal to the onshore section length as percentage of the total length of the Russian sector, is used for the criteria describing the onshore section of the route.

**Method 4.** Scoring which involves weighting factors for all the criteria and the ratio factor for offshore/onshore sections of the route.

- As with Method 2, various criteria are assigned different indicator roles, also expressed by the weighting index W with values of 1 to 5. Besides, this method also involves the ratio of the offshore section to its onshore section length L1 and L2.
- An advantage by any of the criteria scores a routing option is determined through multiplication of the corresponding weighting index W (from 1 to 5 points) and, correspondingly, L1 or L2, depending on whether that criterion is applied to the offshore or onshore section.
The results of comparative assessment of environmental hazard of the two route options performed using four competitive methods

<table>
<thead>
<tr>
<th>№№</th>
<th>Comparative assessment method</th>
<th>M-ment Unit</th>
<th>Option A</th>
<th>Option B</th>
<th>Ratio A/B</th>
<th>Best Option</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Scoring which does not involve weighting factors for the criteria, or the ratio factor for offshore/onshore sections of the route</td>
<td>Points</td>
<td>213</td>
<td>109</td>
<td>1,95</td>
<td>A</td>
</tr>
<tr>
<td>2</td>
<td>Scoring which does involve weighting factors for all the criteria but not the ratio factor for offshore/onshore sections of the route</td>
<td>Points</td>
<td>877</td>
<td>408</td>
<td>2,15</td>
<td>A</td>
</tr>
<tr>
<td>3</td>
<td>Scoring which does not involve weighting factors for the criteria but does involve the ratio factor for offshore/onshore sections of the route</td>
<td>Points</td>
<td>182</td>
<td>77</td>
<td>2,36</td>
<td>A</td>
</tr>
<tr>
<td>4</td>
<td>Scoring which involves weighting factors for all the criteria and the ratio factor for offshore/onshore sections of the route</td>
<td>Points</td>
<td>758</td>
<td>290</td>
<td>2,61</td>
<td>A</td>
</tr>
</tbody>
</table>

- Resulting scores of both options and its ratio vary depending on the comparison method.
- Differences of two compared options scores are less contrast when using the simplest method of points summing, excluding indicator value of each criteria.
- Accounting of criteria diagnostic value differences using weighting factors obviously increases the ability to comparison: score ratio of estimates considerably increases.

- Additional accounting of features share contribution characterizing offshore (expressed dominant) and onshore (relatively small) sections of the route shows these differences more clearly.
- Nevertheless, significant nature protection benefits of option A are rather obvious in case of each of these four comparison methods application.
Quantitative characteristics (environmental criteria) for comparative assessment of possible port locations using cluster analysis

| Distance to the nearest residential constructions |  |
| Land status |  |
| The distance to the nearest nature reserve |  |
| Total volume of dredging |  |
| Volume of dredged grounds suitable for land filling |  |
| Total volume of land reclamation |  |
| Abandoned water area |  |
| Annual sedimentation in port channel and operational waters |  |
| Periodicity of required repair dredging |  |
| Distance to the nearest habitats of protected species |  |
| Distance to the nearest regular congregation of aquatic birds |  |
| Distance to the nearest spawning area of valuable fish species |  |
| Environmental payments during construction works |  |
| Environmental payments during exploitation |  |
| Damage to terrestrial and semi-aquatic organisms (including organisms of protected areas) |  |
| Damage to water biological resources |  |
| Euclidean distances between initial and expected state of the environment |  |
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Cluster analysis of the aggregate characteristics of the environmental impact of four possible sea port locations.

Possible locations of deepwater port:

1- Gulf of Danzig
2,3 – Sea coast bay
4 – the North Cape, Balga
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1

Damage $U$ \textit{(traditional evaluation)}:

\[ R = \sum_{i=1}^{n} R_i = \sum_{i=1}^{n} \left( \xi_i \times U_i \times p_i \right) = \sum_{i=1}^{n} \left( \xi_i \times U_i \times \prod_{j=1}^{k} p_{ij} \right) \]

- $n$ – quantity of analyzed alternative scripts of environmentally hazard events caused by object impact;
- $p_{ij}$ – probability of the $i$-th script realization from $k$ subsequential events;
- $R_i$ – probable environmental damage from realization $i$-th script in cost expression;
- $U_i$ – full value of environmental damage in natural expression;
- $\xi_i$ – coefficient for conversion of damage in natural expression to cost expression with regard to concrete composition and structure of final recipients of the influence.

2

Expected damage $R$ \textit{(based on environmental risk analysis)}:

\[ R = \sum_{i=1}^{n} R_i = \sum_{i=1}^{n} \left( \xi_i \times U_i \times \prod_{j=1}^{k} p_{ij} \right) \]
The histogram of values of the probable damage caused by influence on the ecosystems of two objects (U, thousands roubles per year)

\[
f = \frac{N \times c}{\sigma \times \sqrt{2\pi}} \times e^{-0.5 \left( \frac{\lg U - \overline{\lg U}}{\sigma} \right)^2}
\]
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**Alternative allocation of Avantports**

**Scheme of the Avantports’ allocation**

**Alternative I**

**Scheme of the Avantports’ allocation**

**Alternative II**

a: alternative I - 14 objects;  
b: alternative II - 15 objects.
Example of assessment of expected water area roiling zones as a result of dredging operations during Avantports construction at one of the alternatives concerning possible hydrometeorological conditions.
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Dependence of total environmental payments ($U$) and damage to fishing industry ($U_f$) from volume of soil extracted during dredging ($V$)
Previous experience and prospects of using certain quantitative methods for the environmental assessment of hydraulic engineering constructions during the design process.

Dependence of total environmental payments \((U)\) and damage to fishing industry \((U_f)\) from reclaimed territory area \((S)\)

**Graphs showing the relationship between environmental payments and reclaimed area.**
Dependence of relative environmental payments’ value (U/V, U/S) from volume of soil extracted during dredging (V) and from reclaimed territory area (S)

\[
\lg \left(\frac{U}{V}\right) = (4.572 \pm 0.056) - (0.305 \pm 0.044) \times \lg V; \ r = -0.49
\]

\[
\lg \left(\frac{U}{S}\right) = (5.175 \pm 0.103) - (0.169 \pm 0.097) \times \lg S; \ r = -0.22
\]
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The histogram of relative environmental payments (U/V, roubles per m$^3$; U/S, roubles per m$^2$)

<table>
<thead>
<tr>
<th>Type of distribution</th>
<th>U/V</th>
<th>U$_f$/V</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>explained variance, %</td>
<td>Kolmogorov test</td>
</tr>
<tr>
<td>normal</td>
<td>81,7</td>
<td>3,83</td>
</tr>
<tr>
<td>lognormal</td>
<td>99,9</td>
<td>0,11</td>
</tr>
<tr>
<td>Pareto</td>
<td>99,7</td>
<td>0,40</td>
</tr>
<tr>
<td>exponential</td>
<td>99,8</td>
<td>0,29</td>
</tr>
<tr>
<td>Maxwell</td>
<td>0,2</td>
<td>9,03</td>
</tr>
</tbody>
</table>

U/V $\approx 33 \pm 5$ RUB/m$^3$

<table>
<thead>
<tr>
<th>Type of distribution</th>
<th>U/S</th>
<th>U$_f$/S</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>explained variance, %</td>
<td>Kolmogorov test</td>
</tr>
<tr>
<td>normal</td>
<td>60,4</td>
<td>3,16</td>
</tr>
<tr>
<td>lognormal</td>
<td>99,6</td>
<td>0,10</td>
</tr>
<tr>
<td>Pareto</td>
<td>98,1</td>
<td>0,62</td>
</tr>
<tr>
<td>exponential</td>
<td>98,2</td>
<td>0,63</td>
</tr>
<tr>
<td>Maxwell</td>
<td>-15,2</td>
<td>5,94</td>
</tr>
</tbody>
</table>

U/S $\approx 179 \pm 44$ RUB/m$^2$
Opportunities to reduce environmental hazards of port development by regulating the environmental risk at the pre-stage

Classification of hydroconstruction impact on the environment:

1) **Low impact**: 
   \[ U/V < 0.1 \text{ €/m}^3; \]
   \[ U/S < 0.1 \text{ €/m}^2 \]

2) **Moderate impact**: 
   \[ 0.1 \leq U/V < 1.0 \text{ €/m}^3; \]
   \[ 0.1 \leq U/S < 1.0 \text{ €/m}^2 \]

3) **Significant impact**: 
   \[ 1 \leq U/V < 10 \text{ €/m}^3; \]
   \[ 1 \leq U/S < 10 \text{ €/m}^2 \]

4) **Intensive impact**: 
   \[ U/V \geq 10 \text{ €/m}^3; \]
   \[ U/S \geq 10 \text{ €/m}^2 \]

\( U/V \) and \( U/S \) - environmental costs per unit volume of soil and formed territory.
Correction of predicted environmental payments values after hydraulic works according to imperative environmental factors

\[ \lg(U/S)_{\text{max}} = (3.579 \pm 0.095) + (1.191 \pm 0.074) \times v; \quad r=0.96 \]

\[ (U/S)_{\text{max}} = (3796 \pm 926) \times v^{(1.191 \pm 0.074)} \]

\( v \) – mean current speed

\[ \ln(U/S)_{\text{max}} = (6.207 \pm 0.211) - (7.17 \pm 0.90) \times d; \quad r=0.97 \]

\[ (U/S)_{\text{max}} = (496 \pm 116) \times e^{-(7.17 \pm 0.90) \times d} \]

\( d \) – mean particle size

Examples of the maximum possible values of the relative environmental costs per unit of created territory (U/S, RUB/m²) determined by current speed (v, m/s) and average particle size (d, mm). Contour curves (according to data marked in red) are approximated by equations.
Thank you for your attention!

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