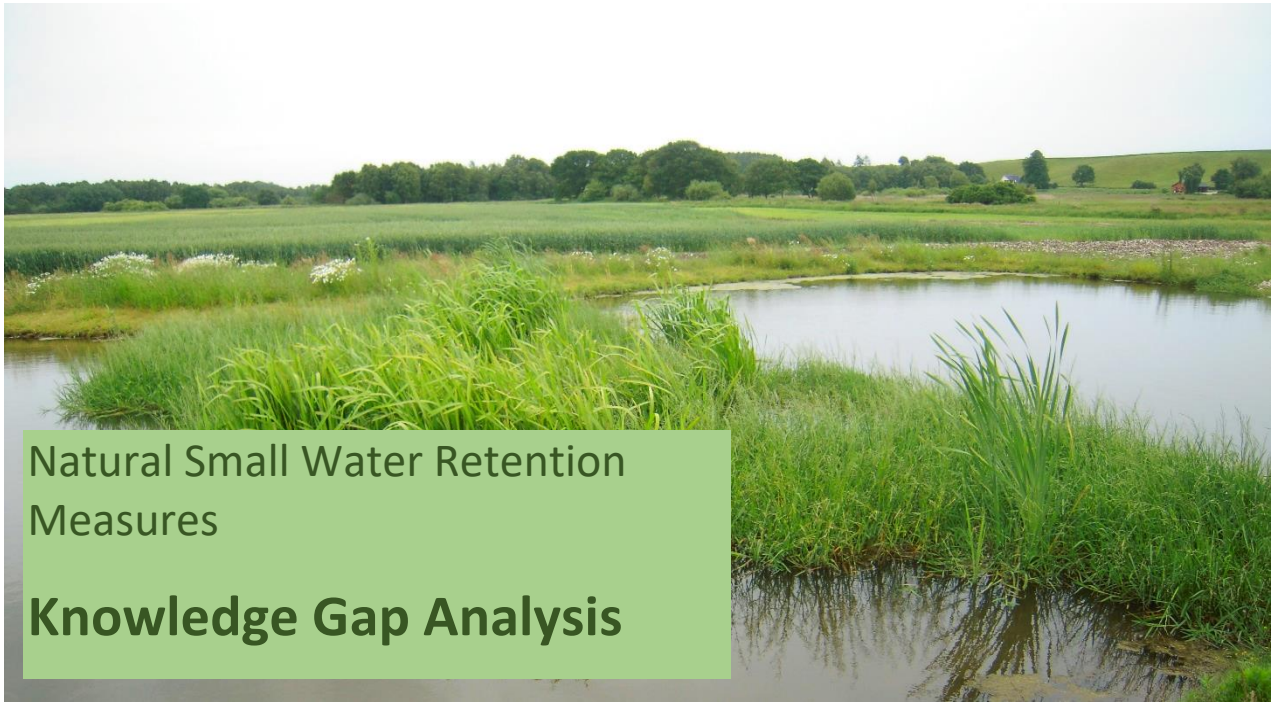
Global Water Partnership
Central and Eastern Europe

Integrated Drought Management
Programme in Central and Eastern Europe



Natural Small Water Retention Measures

Knowledge Gap Analysis

Name of the activity	Natural Small Water Retention Measures (demonstration project)
Activity leader	Tomasz Okruszko Warsaw University of Life Sciences, Poland
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Type of the ouptuts	Analysis / Report
Purpose of the output	To search for the knowladge gaps in N(S)WRMs
Duration of the activity	October 2016 – December 2016

CONTENT

1. Introduction

Demostration project on Natural Small Water Retention Measures (NSWRM) started in 2013 within Integrated Drought Mangement Porgramme for CEE (IDMP CEE).
Experts from Poland, Slovakia, Hungary and Slovenia carried out the project during the period 2013–2015. Main outcome is guidelines on Natural small water retention measures – combining drought mitigation, flood protection and biodiversity conservation. The guidelines provide details on technical and non-technical measures to increase the natural small water retention, selection of the catchment area, evaluation of the measures and their connection to river basin management, and flood risk management and drought management plans. It summarizes experiences from implemented projects in Poland, Slovakia, Hungary, Slovenia including best practices on combined effects and involvement of stakeholders. The Guidelines compliment the Case Studies, examples of different small retention measures already in action from CEE region.
In 2016 partners prepared a full-scale project proposal as a follow up of the demonstration project. Main objective of the new project (Framework for improving water balance and nutrient mitigation by applying small water retention measures – FramWat) is to strengthen the regional common framework for floods, droughts and pollution mitigation by increasing the buffer capacity of the landscape using the N(S)WRM approach in a systematic way. FramWat project supports idea for using the landscape features to help solving environmental problems in water bodies in the sustainable way. The innovative way for doing so is development of methods which translate existing knowledge about N(S)WRM features into river basin management practice. This will result in improving water balance, decreasing sediment transport, enhancing nutrients re-circulation. The propose measures will improve the protection of natural heritage, which is an added value comparing to the traditional approach. FramWat will provide decision makers with appropriate tools to incorporate N(S)WRM into the next cycle of River Basin Management Plans. Additionally, the project will provide guidance and raise awareness about the importance of horizontal integration of different planning frameworks.
New project proposal is based on the conclusions and results from the demonstration project and is trying to capitalize results from previous/similar projects. On of the main background document was also this Knowledge Gap Analysis, which helped with identification of which parts/actions/information about NSWRM is not yet covered by different research papers, etc. so that those topics could be addressed in the new project.

2. Methodology

To explore the existing knowledge on the SWRM we used the Web of Science Database, which generally contains the highest-quality research results from the whole spectrum of the scientific disciplines. The amount of existing knowledge is certainly unpredictable in terms of very new approaches and paradigms emerging within hydrology, water management science and water-related problems generally. Therefore we designed a simple algorithm to browse the database via following predefined combinations of keywords selected from the Guideline on NSWRM (see Tables 2-3 within the Guidelines) trying to address all aspects of NSWRM effectiveness, i.e. regarding the drought and flood mitigation and protection, nutrients migration and biodiversity conservation. We used the advanced search options within the WOS Database search machine (e.g. TS =" landscape retention" AND "afforestation") without filtration of results but specifying the maximum number of result papers (14) – ordered by times cited within other literature sources. Then we chose the most relevant papers in terms of their main objectives, problems solved or motivations of the research, methodology used (including site specification), main results and conclusions. We performed the statistics of the frequency of problems addressed by selected papers (literature sources), which is shown in Table 1.

3. Results – table of statistics

Keyword combination		Total number of papers analysed	No. of papers important for catchment hydrology or urban areas hydrology	No. of papers important for agriculture, forestry and pasture	No. of papers important for chemistry of environment, pollution and sedimentation (hydromorpho)	No. of papers important for biodiversity	No. of papers important for natural reserves, tourism, fire-risk	No. of papers important for policies, economy and development	Link to summary of the research review
landscape retention	afforestation	14	3	5	4	7	4	5	Link
groundwater retention	floodplain restoration	18	16	18	18	11	5	2	Link
soil water retention	soil structure	21	7	21	0	1	0	0	Link
soil water retention	organic matter	14(mulching)+ 30 (org.matter)	19	44	11	4	0	27	Link
soil water retention	tillage	16	9	16	0	0	0	6	Link
groundwater retention	restoration wetlands	32	26	1	25	4	1	6	Link**Error! eference source not found.**
groundwater retention	riparian buffers	44	22	13	43	4	0	7	Link
aquifer retention	wetlands	36	22	5	26	2	1	2	Link
landscape retention	biofiltration	2	2	0	2	0	0	0	Link

landscape retention	polders	5	5	2	3	1		1	Link
landscape retention	ponds	100	31	30	37	23	26	9	Link
floodplain restoration	nutrient retention	56	21	16	32	7	13	11	Link
landscape retention	terracing	16	3	7	4	1	8	2	Link
landscape retention	retaining walls	1	0	0	0	1	1	0	
water retention	biodiversity	350	59	135	97	311	118	39	Link
floodplain restoration	ecosystem services	117	27	50	28	42	28	10	Link

3.1. Landscape retention & Afforestation

Rooftop gardening (or green roof establishment) is an urban greening afforestation method that has many environmental, economic, and urban landscaping benefits (e.g. flood protection, microclimate improvement – smoothing temperature annomalies, human physical and psychological health, etc.). These benefits were proved by microclimate monitoring, hydrological and questonaires performances.
Source:
Performance of herbaceous Evolvulus pilosus on urban green roof in relation to substrate and irrigation.
By: Kanechi, M (Kanechi, Michio); Fujiwara, S (Fujiwara, Shinya); Shintani, N (Shintani, Naoki); Suzuki, T (Suzuki, Takeshi); Uno, Y (Uno, Yuichi): URBAN FORESTRY & URBAN GREENING, Volume: 13 Issue: 1 Pages: 184-191, Published: 2014

In the case of paramo to pine transitions, the biophysical response includes a loss of soil carbon, nitrogen, and water retention capacity, implying important trade-offs between the ecosystem services provided by paramos and those provided by pine plantations. These results suggest that **both the existing land cover prior to forest transition and the type of forest cover established during transition merit more attention in forest transition theory.**
Source:
Grasslands to tree plantations: Forest transition in the andes of Ecuador.
By: Farley, KA (Farley, Kathleen A.) ANNALS OF THE ASSOCIATION OF AMERICAN GEOGRAPHERS
Volume: 97 Issue: 4 Pages: 755-771, Published: DEC 2007.

The species composition, occurrence and diversity of understored of forestry plantations and semi-natural secondary forests in a warm-temperate region in southeastern Kyushu, Japan. Cluster analysis and detrended correspondence analysis, indicated that **plant species composition in forest stands was primarily influenced by the previous land-use history (as meadows or coppices) compared with either the current status of the stand (semi-natural forest or plantation) or site micro-topography.** Species richness, however, was higher in plantations and stands developing on former meadow sites. This was true of perennial forbs and climbing plants, but not the evergreen species which were originally common in native woodland of the region. **It was concluded that previous land-use has a significant effect on the species composition and diversity of forest, persisting even after the establishment of conifer plantations, and that the restoration of the original 'woodland' species composition and diversity will require the retention of efficient seed sources near stands which have developed on land previously cleared of native forest cover.**
Source:
Effects of previous land-use on plant species diversity in semi-natural and plantation forests in a warm-temperate region in southeastern Kyushu, Japan
By: Ito, S (Ito, S); Nakayama, R (Nakayama, R); Buckley, GP (Buckley, GP)
FOREST ECOLOGY AND MANAGEMENT, Volume: 196 Issue: 2-3 Pages: 213-225, Published: JUL 26 2004

Retention of interconnected, remnant grassland linkages is proposed here to reduce the adverse effects of alien pine afforestation in Afromontane grasslands. Butterfly species richness and abundance in the lesser disturbed grassland remnants within the afforested area were similar to those of the surrounding natural grasslands. In contrast, butterfly species richness, but not necessarily abundance, decreased significantly in the highly disturbed sites, both in the grassland linkages and outside. Retention of wide, quality grassland linkages are a way forward to maximise biodiversity alongside agroforestry.

Source:
Quality of remnant indigenous grassland linkages for adult butterflies (Lepidoptera) in an afforested African landscape.
By:Pryke, SR (Pryke, SR); Samways, MJ (Samways, MJ) BIODIVERSITY AND CONSERVATION
Volume: 12 Issue: 10 Pages: 1985-2004, Published: OCT 2003

In the Ethiopian highlands, deforestation and land cover changes have been going on for millennia. Soils from the elevational gradient were analyzed for different soil chemical properties and results were compared with concentrations of C and N. **The mid-altitude soils with several hundred years of undisturbed forest cover tended to have higher concentrations of organic matter, available and total N and total and exchangeable Ca than the high- and low-elevation forests, which have been disturbed more frequently. The forest soils subjected to disturbances thus tended to have lower CEC and nutrient retention capacity. The study indicates that the variation in the chemistry of forest soils along the altitudinal gradient in the Menagesha forest is related to the historical patterns of land use changes, and not to lithologically related variations**. It is also suggested that the presence of forest in this otherwise open landscape leads to accumulation of base cations in the soil, especially Ca, due to deposition from the atmosphere.
Source:
Historical land use pattern affects the chemistry of forest soils in the Ethiopian highlands
By:Eshetu, Z (Eshetu, Z); Giesler, R (Giesler, R); Hogberg, P (Hogberg, P)
GEODERMA, Volume: 118 Issue: 3-4 Pages: 149-165, Published: FEB 2004

The scenic quality of clear-cutting areas can be substantially improved if there remains an adequate volume of mature retention trees that are in good condition**.**
Source:
Scenic impacts of retention trees in clear-cutting areas
By:Tonnes, S (Tonnes, S); Karjalainen, E (Karjalainen, E); Lofstrom, I (Lofstrom, I); Neuvonen, M (Neuvonen, M)
SCANDINAVIAN JOURNAL OF FOREST RESEARCH, Volume: 19 Issue: 4 Pages: 348-357, Published: APR 2004

Woodpecker conservation benefits from an **increase of habitat heterogeneity**, particularly by the retention of native woodland patches within the plantation matrix.
Source:
Retention of native vegetation within the plantation matrix improves its conservation value for a generalist woodpecker
By: Barrientos, R FOREST ECOLOGY AND MANAGEMENT, Volume: 260 Issue: 5 Pages: 595-602,Published: JUL 30 2010

This article details the process of integrating models to answer a specific policy-driven question: **What could be the impact of proposed Natural Water Retention Measures (NWRMs) on Europe's Green Infrastructure (GI)?'** Three indicators associated with the morphology of GI are computed in order to assess the model outputs for 2030. The indicators are computed to answer the following questions: (1) How is the quantity of GI affected by each of the NWRM, and what proportion of that GI is most valuable? (2) What is the location of the most critical nodes and connectors of GI, and what land-use conversions occur under these? (3) Are the average components getting larger or smaller? Whereas the grassland measure results in the largest net increase of GI, the afforestation measure results in the overall largest number of hectares of key nodes and links within the network. Land conversions occur under the critical GI nodes and links, with a large increase in agricultural areas, especially for the riparian measure under critical nodes and the grassland measure under critical links. Also predominant is the swapping of land from pasture to forest under critical links with the afforestation measure. The

riparian measure most increases the average size of GI components, and all three measures contribute to bridging two large components which were divided in the 2006 land-use map, thus increasing the size of the largest component by more than 50%.
Source:
A land-use-based modelling chain to assess the impacts of Natural Water Retention Measures on Europe's Green Infrastructure
By: Mubareka, S (Mubareka, Sarah)[1] ; Estreguil, C (Estreguil, Christine)[1] ; Baranzelli, C (Baranzelli, Claudia)[1] ; Gomes, CR (Gomes, Carla Rocha)[1] ; Lavalle, C (Lavalle, Carlo)[1] ; Hofer, B (Hofer, Barbara)[1]
INTERNATIONAL JOURNAL OF GEOGRAPHICAL INFORMATION SCIENCE, Volume: 27 Issue: 9 Pages: 1740-1763
Special Issue: SI, Published: SEP 1 2013

For forest land use, it has been stated that the promotion of sustainable forest management and the increase of forest land via afforestation will considerably improve flood retention. Notably, the latter should be efficient to re-establish the natural water retention potential in anthropogenically disturbed river basins and to decrease the human-made contribution to flood generation. However, due to obvious physical limitations (such as soil depth, porosity, and conductivity) and the frequent lack of available land for forest expansion, the role of afforestation in flood mitigation has been a topic of strong debate. This study assesses the 'forest effect' based on model calculations and suggests visualisations to communicate the results. **For a catchment (6.8 ha) and two well-founded land-use scenarios, it could be shown that the peak reduction for flood events varies from 3% to 70% and is highly related to the event characteristics (especially pre-event soil moisture).** The cross compliance to other protection aims (i.e. water quality and soil protection) is part of the considerations.
Source:
Potentials and limitations of natural flood retention by forested land in headwater catchments: evidence from experimental and model studies.
By: Wahren, A (Wahren, A.)[1] ; Schwarzel, K (Schwaerzel, K.)[1] ; Feger, KH (Feger, K. -H.)[1]
JOURNAL OF FLOOD RISK MANAGEMENT, Volume: 5 Issue: 4 Pages: 321-335, Published: DEC 2012

3.2. Groundwater retention & Floodplain restoration

Good management of the uplands is essential and effective buffer zones along the streams draining the basin will complete the task of water quality protection. Most basin drainage moves through the riparian zones of firs- and second-order headwaters streams. For larger streams, protect the flood plains. Several zones of buffer vegetation are most effective. A narrow grass strip at the upland edge traps suspended particulates and phosphorus. A wider zone of woody vegetation traps nitrate and both cools and provides natural organic matter to the receiving waters. Contour the buffer surface to avoid concentrated storm flow and periodically remove sediment berms that develop. For a completely degraded riparian zone, it is essential to provide soils of the right porosity and organic C content. Sub-soil need to be permeable and to have a reasonable groundwater retention time. High organic carbon is required to develop a low redox potential. Do provide short-term protection from erosion. Only add native species, exotic plants must be eradicated. Control excessive activity of wild game (beavers).
Source:
Principles of planning and establishment of buffer zones.
By: David L. Correll. Ecological Engineering 24 (2005), Pages: 433-439,

Soil compaction that follows the clearing of forest for cattle pasture is associated with lower hydraulic conductivity and increased frequency and volume of overland flow. Frequency of storm flow and overland flow has doubled in pasture. However the stormflow volume has increased 17-fold. This resulted from overland flow generation over larger pasture areas, while overland flow generation in

the forest was spatially limited and was observed only very near the stream channel. In both catchments, stormflow was generated by saturation excess because of perched water tables and near-surface groundwater levels. These results suggest that deforestation for pasture alters fundamental mechanisms of stormflow generation and may increase runoff volumes over wide regions.
Source:
Influence of land-use change on near-surface hydrological processes: Undisturbed forest to pasture.
By: Sonja Germer, Christopher Neill, Alex V. Krusche, Helmut Elsenbeer. Journal of Hydrology 380 (2010), Pages: 473-480,

Increases in ground water total dissolved phosphorus following harvest are unlikely due to the large adsorption affinity of mineral soils. Phosphorus-rich surface soils have a large potential for phosphorus release to surface water but this does not differ between harvested and forested areas. Sub-humid climate conditions and rapid aspen regeneration lead to soil moisture deficits and limited surface runoff which may reduce harvesting effects on P mobilization on the Boreal Plain.
Source:
Soil, surface water and groundwater phosphorus relationships in a partially harvested Boreal Plain aspen catchment.
By: M.L. Macrae, T.E. Redding, I.F. Creed, W.R. Bell, K.J. Devito. Forest Ecology and Management. 206 (2005), Pages: 315 - 329,

Understanding and predicting the water quality interactions between the shallow aquifer and surface water is a key component in meeting current environmental regulations and fine-tuning ENP wetland restoration while still maintaining flood protection for the adjacent developed areas. Dynamic factor analysis (DFA), technique for the study of multivariate non-stationary time series, was applied to study fluctuations in groundwater quality in the area. DFA results showed that groundwater concentration of three of the agrochemical species studied ($N\text{-}NO_3^-$, $P\text{-}PO_4^{3-}$ and total P) were affected by the same explanatory variables (water table depth, enriched topsoil, and occurrence of a leaching rainfall event, in order of decreasing relative importance).
Source:
Dynamic factor analysis of groundwater quality trends in an agricultural area adjacent to Everglades National park.
By: R. Munoz-Carpena, A. Ritter, Y.C. Li. Journal of Contaminant Hydrology 80 (2005), Pages: 49 - 70,

Site attributes such as hydric soil status (soil wetness) and geomorphology, affect the interaction of nitrate-enriched ground water with portions of the soil ecosystem possessing elevted biogeochemical transformations rates (i.e. biologically active zones). High ground water nitrate-N removal rates were restricted to hydric soils. Riparian sites located on outwash and organic/alluvial deposits have high potential for nitrate-enriched ground water to interact with biologically active zones. In till deposits, ground water nitrate removal capacity may be limited by the high occurrence of surface seeps that markedly reduce the time available for boil. Transformations to occur within the riparian zones. Landscape controls on riparian nitrate removal in different climatic and physiographic regions must be determined and translated into available spatial databases. Riparian zones display wide variation in their ground water nitrate removal capacity. Models are increasingly in demand to help estimate Total Maximum Daily Loads and to target remediation efforts. Through the use of GIS analyses, we can target management, restoration and protection of stream reaches where riparian buffers can have a marked effect on watershed nitrate dynamics. Water table dynamics and soil wetness are critical components in ground water nitrate removal. Plant roots and living microbes capable of taking up nitrate are more abundant in near-surface soil horizons. In riparian zones with hydric soils, the water table typically rises within 30 cm of the ground surface during much of the year. Restoration of urban riparian zones must consider efforts to reverse the effects of urban hydrology on water table levels.

Source:
Landscape attributes as controls on ground water nitrate removal capacity of riparian zones.
By: A.J. Gold, P.M. Groffman, K. Addy, D.Q. Kellogg, M. Stolt, A.E. Rosenblatt. Journal of the American Water Resources Association, 37, 2001, Pages: 1457 - 1464,

The two valley bottom swamps were connected to local aquifers but the upland-wetland connections was continuous in the catchment with deeper till and ephemeral in the catchment with thin till-rock ridges. Groundwater movement through the wetlands was restricted mainly to the surface peat layer in both wetlands, because a large portion of inputs from shallow soil layers and stream inflows enter near the peat surface. However, differences in upland-wetland connections resulted in contrasting hydrologic regimes in the to swamps. In summer, upland inputs were absent in the catchment with thin till-rock ridges, resulting in cessation of baseflow and a low water table that varied in response to variations in rainfall. Continuous upland inputs throughout the summer in the catchment with deeper tills (1-3m) sustained baseflow and kept the water table near the peat surface. The study demonstrates the control of morphology and shallow subsurface geology on the hydrology of valley bottom swamps influenced by local aquifers.
Source:
Groundwater-surface water interactions in headwater forested wetlands of the Canadian Shield.
By: K.J. Devito, A.R. Hill, K. Addy, N. Roulet. Journal of Hydrology, 181, 1996, Pages: 127 - 147,

3.3. Soil water retention & Soil structure

- Seeds of two autochtonous trees, Banksia attenuate and B. menziesii were sown across three different treatments of post-mine soils (amendment of mulch, gravel incorporation within the top 50 cm of soil profile, natural reference systems) within the area of operational sand quarry 30 km northeast of Perth, Western Australia.
- Native trees and brush cleared prior to soil extraction can beused as soil amendment to increase water retention and improve seedling establishment in sandy postmine soils
- **The disruption of root morphology by compact postmine soil is only indirectly associated with seedling mortality. In field settings where water is the limiting variable, soil impedance as it affects water availability is more influential to seedling establishment than physical impedance itself.**

Source:
Increasing soil water retention with native-sourced mulch improves seedling establishment in postmine Mediterranean sandy soil. By: S.M. Benigno, K.W. Dixon, J.C. Stevens. Restoration Ecology, 21, 5, 2012, Pages: 617 – 626.

- The soils studied were Haplic Phaeozem and Eutric Fluvisol situated in SE Poland, where the steppe plants provided large amount of organic matter and the fluvial outwash were the main soil-forming factors.
- The degree of water saturation in beds of aggregates < 0.25, 0.25–0.5 and 0.5-1 mm compared to beds of aggregates 1–3, 3–5 and 5–10 mm was greater at higher values of pressure head for both soils, and for undisturbed soil it was greater for the Haplic Phaeozem than for the Eutric Fluvisol at lower values of pressure heads.
- The aggregates of undisturbed soils exhibited multi-peak PSD. The pore radius peaks within the textural (primary) pore system were more defined in beds of aggregates < 0.25 mm than

in beds of coarser aggregates, whereas in the case of the structural and macropore peaks it was often the reverse.

- **The WRCs had inflection points, the number and shape of which are largely influenced by the size range of aggregates, depending of the soil type to a different extent.**
- **The results of this study can be valuable in linking the soil pore system to storage and transmission properties of tilled soils.**

Source:
The effect of aggregate size on water retention and pore structure of two silt loam soils of different genesis. By: J. Lipiec, R. Walczak, , B. Witkowska-Walczak, A. Nosalewicz, A. Slowinska-Jurkiewicz, C. Slawinski. Soil&Tillage Research, 97, 2007, Pages: 239 – 246.

- The research used the National Resource Conservation Service database (2140 samples) to evaluate the potential for structural and consistence properties to serve as predictors of soil hydraulic properties.
- Plasticity class, the grade class and dry consistency class were leading predictors of water retention at both, -33 kPa and -1500 kPa matric potentials. The accuracy of estimates from structural and consistence parameters was lower than from textural classes. The accuracy improvement by incorporation of plasticity and structure parameters (together with texture) into prediction was small but significant
- **Increase in plasticity, stronger grade for nonplastic soils, and harder dry consistency lead to the increase of water retention.**

Source:
Soil consistence and structure as a predictors of water retention. By: W.J. Rawls, Ya. A. Pachepsky. Soil Sci. Soc. Am. J. 66, 2002, Pages: 1115 – 1126.

- Differences in soil texture, structure and water retention capacity between burnt and unburnt soils were studied in an area affected periodically by forest fires in SE Spain (at altitudes ranging from 100 to 1000 m a.s.l.).
- Greater aggregate stability and smaller clay content was found in burnt soils. Slight differences in climate between the locations hide other effects of fire on these already degraded soils. The most humid site showed considerably greater soil organic matter, which is responsible for greater water retention capacity of this soil (not intensively burnt and unburnt). **Low fire intensities have not appreciably affected the soil properties measured.** However, at the sites, where the burning was more intense, the water retention capacity was greater for unburnt than for burnt soils.
- **As climate, in terms of water availability from precipitation, seems to be the main factor determining the soil quality, and fire alters the available water capacity only if it is very intense, it seems that low intensity fires do not cause any further degradation of the already degraded soils in the type of Mediterranean environment.**

Source:
The roles of texture and structure in the water retention capacity of burnt Mediterranean soils with varying rainfall. By: C.B. Fayos, Catena. 31, 1997, Pages: 219 – 236.

- **Soil structure maintains prime importance in determining the ability of soils to carry out essential ecosystem functions and services.**
- Study quantifies the newly formed structure of 22-mo field incubated physically disturbed (2-mm sieved) samples of varying caly mineralogy (illite, kaolinite, and smectite) amended with organic material (7.5 t/ha). The newly formed structure was compared with sieved repacked samples and natural intact samples.
- Assessment and comparison of structural complexity and organization was done using water retention (pore size distribution), soil gas diffusivity, air permeability, and derived pore network complexity parameters.
- Significant decreases in bulk density and increases in pores > 100 m were observed for incubated samples cpompared with sieved repacked samples (SR). The proportion of these pores also increased in the order: smectite < illite < kaolinite, with no effect of organic amendment.
- The soil pore organization was similar for both natural and incubated samples, but pore network complexity increased in order: SR < incubated < natural soils. Finally, the air permeability percolation threshold corresponding to the physically based diffusion threshold increased with structural complexity. **Lack of a clear effect of organic amendment for incubated samples suggests using higher application rates!**

Source:
Water retention, gas transport, and pore network complexity during short-term regeneration of soil structure. By: A. Emmanuel, P. moldrup, P. Schjonning, L.Wollesen de Jonge. Soil Sci Soc. Am. J. 77: 2014, Pages: 1965 – 1976.

3.4. Soil water retention & Organic matter

- The research was performed in Central New York State, USA in forests operated by Cornell University.
- Earthworms have been shown to produce contrasting effects on soil carbon (C) and nitrogen (N) pools and dynamics. They alter the timing anfd location of the flow of C and N from litter to microbial biomass to organic matter, with important effects on the capacity of soils to sequester these elements, with significant differences between communities dominated by *Lumbricus terrestris* and *L. rubellus.*
- Plots dominated by *Lumbricus rubellus* or *L. terrestris* have markedly lower total soil C than uncolonized plots. Total soil N pools in earthworm colonized plots were reduced much less than C, but significantly so in plots dominated by *L. rubellus*.
- Microbial biomass C and N were higher in earthworm-colonized plots and more C and N were recovered in microbial biomass and less was recovered in mineralizable and inorganic N pools in these plots.
- Earthworms increase the carrying capacity of soil for microbial biomass and facilitate the flow of N from litter into stable stable soil organic matter. However, declines in soil C and C:N ratio may increase the potential for hydrologic and gaseous losses in earthworm-colonized sytes under changing environmental conditions.

Source:

Warthworms increase soil microbial biomass carrying capacity and nitrogen retention in northern hardwood forests. By: P.M. Groffman, T.J. Fahey, M.C. Fisk, J.B. Yavitt, R.E. Sherman, P.J. Bohlen, J.C. Maerz. Soil Bilogy&Biochemistry, 87, 2015, Pages: 51 – 58.

- There is an interest to integrate livestock with crop production systems what warrants further understanding of the impacts of manure application on soil physical processes and properties such as soil's susceptibility to compaction and water retention
- 71-yr cumulative impact of beef cattle manure and inorganic N fertilizer application to conventionally tilled and irrigated corn on soil compactibility, water retention, available water and soil organic carbon (SOC) on very fine sandy loam at the plots of the University of Nebraska has been evaluated.
- Manure application improved soil properties at the 0- to 30-cm depth, but inorganic fertilization had no effect. Manure application reduced maximum bulk density by 6% and increased soil critical water content (at which maximum compactibility occurs) by 17% indicating that manured soils can be slightly less susceptible to compaction and trafficked at higher water content without being excessively compacted compared with nonmanured plots.
- Manured plots also retained 18% more soil water at -0.033 MPa and 21% more at -1.5MPa.
- The SOC concentration has been increased two-fold with manure addition and was negatively correlated (r> -0.77) with soil compactibility and positively (r> 0.72) with water retention.

Source:
Cattle Manure Application Reduces Soil Compactibility and Increases Water Retention after 71 Years. By: H. Blanco-Canqui, G.W. Hergert, R.A. Nielsen. Soil Sci. Soc. Am. J., 79, 1, 2015, Pages: 212 – 223.

- Field experiment was located on the Macdonald Research Farm, Ste. Anne de Bellevue, Quebec, Canada. Sixteen factorial combinations of tillage (conventional tillage – CT or no till NT), crop rotations (continuous maize – CC or soybean/maize – SC) and fertilizer sources (0, 15, 30, and 45 t/ha of composted cattle manure balanced with inorganic fertilizers) were evaluated in terms of aggregation and nutrient retention in sandy-loam soil.
- Soil aggregation plays a crucial role in soil physicochemical and biological processes.
- Four years after the treatments were established, the proportion of large water-stable aggregates (> 2 mm) was greater in the NT system, suggesting that NT increased soil aggregation compared to the CT system. There was no difference in soil aggregation between different rotations. The application of 30 and 45 t/ha/year of composted manure produced more large water stable aggregates than inorganic fertilizers.
- **Total C, N and P concentrations were at least 3 times higher in water-stable microaggregates than water stable macroaggregates. Microaggregate fraction is considered to be a sink for these nutrients, but may also be susceptible to soil erosion. Transport processes preferentially remove the microaggregate fraction from agroecosystems what can lead to nutrient loading in adjacent ecosystems. It will be important to minimize the quantities of microaggregate lost from agroecosystems to prevent pollution of waterways and other ecosystems sensitive to nutrient loading.**

- It was concluded that adopting no tillage and applying composted manure increases soil aggregation and nutrient retention in a sandy-loam soil under maize production.

Source:
No-tillage and manure applications increase aggregation and improve nutrient retention in sandy-loam soil.. By: Y. Jiao, J.K. Whalen, W.H. Hendershot. Geoderma, 134, 2006, Pages: 24 – 33.

3.5. Soil water retention & Tillage (crop rotation)

- Research from the Wagga Wagga N.S.W., Australia reports that the soil rotation has significant influence on soil structure and soil physical properties. Chosing the specific herbs or crops in rotation cycles may improve the porous system properties, stability and shear strength of the soil aggregates within the upper root zone (up to 0.18 m depth).
- Crops seem to have different abilities in modifying a range of soil biological and chemical properties, namely microbial biomass, dissolved carbon and soluble cation concentrations.
- The research results support the farmer observations that soil following lupin are easier to manage than those following several other crops including field peas and the significant beneficial effects of canola on soil structure.
- Crop-induced differences in soil structure tended to be short-lived under the conventional cultivation practices, because of the repeated cultivation operations used to prepare a seedbed for the following wheat crop. Adoption of conservation tillage practices, namely direct drilling and reduced tillage may help to preserve the benefits of the alternate crops.

Source:
The influence of crop rotation on soil structure and soil physical properties under conventional tillage. By: K.Y. Chan, D.P. Heenan. Soil&Tillage Research, 37, 1996, Pages: 113 – 125.

- The long-term integrated effect of crop rotation and tillage has been studied on a Canadian silt loam soil at the Elora station in Ontario.
- Topsoil effects of three different rotation systems and two tillage treatments (no tillage and mouldboard ploughing) during the period of 30 years were studied.
- Visual evaluation, penetration resistance and X-ray CT scanning was used to evaluate the soil structure and porosity, penetration resistance for bulk density.
- Poor soil structure was found for no tillage except when combined with a diverse crop rotation. Diverse crop rotation may optimize the the performance of no tillage treatment.
- The quantitative physical properties confirmed the positive effect on intensive tillage on soil structure but showed in general a weak and insignificant effect of rotation.
- Crop yield correlated significantly with the visual soil structure scores.

Source:
Long-term rotation and tillage effects on soil structure and crop yield. By: L.J. Munkholm, R.J. Heck, B. Deen. Soil&Tillage Research, 127, 2013, Pages: 85 – 91.

- Strain S incidence and A. flavus propagules (as important cause of aflatoxin contamination) were quantified periodically in 11 agricultural fields in South Texas from spring 2001 through spring 2003.

- The results suggest it may be possible to manipulate crop rotations in order to reduce aflatoxin severity, and that period of increased soil temperature drive selection of the highly toxigenic S strain of *A.flavus* in warm climates.

Source:
Crop rotation and soil temperature influence the community structure of *Aspergillus flavus* in soil. By: R. Jaime-Garcia, P.J. Cotty. Soil Biology & Biochemistry, 42, 2010, Pages: 1842 – 1847.

- Review paper
- Soil structural heterogeneity is a key determinant of biological diversity and activity of within the soil ecosystem.
- Organic farming generally improves porosity, earthworm abundance and increases aggregate size and development.
- The formation of aggregates is essentially dependent upon a supply of organic matter, although the process of aggregation is also strongly dependent on the nature of the soil mineralogy. The proportion of clay (especially the 2:1 clay minerals) contained in the soil is important in determining the extent of aggregation.
- Increase in the number of small and medium-sized pores in compost-amended soils indicates a better structure and potential plant growth.
- Typically, root extension shows a negative curvilinear relationship to penetrometer resistance. High mechanical impedance as a result of compaction results in a slower extension and increased radial thickening of roots.
- Crop rotations are considered a tool to maintain sustainable crop production.
- The sequence of crops in rotation not only influences the removal of nutrients from soil, but also the return of crop residues, the development and distribution of biopores and the dynamics of microbial communities. These processes contribute to the development of soil structure.
- There is a need for further research in improved quantitative linkages between soil structure and crop growth, the consequences to soil structure and nutrient cycling of crop residue incorporation, developing natural disease suppression, amelioration of subsoils by crop roots, the fate of carbon deposited by plant roots in soil and the fate of organic nitrogen in soil.

Source:
The role of crop rotations in determining soil structure and crop growth conditions. By: B.C. Ball, I. Bingham, R.M. Rees, C.A. Watson, and A. Litterick. Can. J. Soil Sci. Downloade from www.nrcresearchpress.com.

- Soil compaction can be minimized either mechanically or biologically, using plant species with vigorous root systems.
- Soil quality was estimated using the S index and soil water retention curves in Botucatu, Sao Paulo State, Brazil.
- Crop rotation and chiseling were compared in terms of improving soil quality. I was shown by S-index, that use of mechanical chiseling is unnecessary, since after three years the soil physical quality under no-tilled crop rotation and chiseling was similar.
- Crop rotation and chiseling improved soil quality, enhancing the S-index to over 0.035, down to the depth of 20 cm in the soil profile.

Source:
Soil water retention and S index after crop rotation and chiseling. By: J.C. Calonego, C. A. Rosolem. R. Bras. Ci. Solo, 35, pages: 1927 - 1937.

3.6. Groundwater retention & Restoration Wetlands

Restoring urban infrastructure and managing the nitrogen cycle represent emerging challenges for urban water quality. We investigated whether stormwater control measures (SCMs), a form of green infrastructure, integrated into restored and degraded urban stream networks can influence watershed nitrogen loads. Analysis suggests that some major predictors for watershed N retention were: (1) streamwater and groundwater flux through stream restoration or stormwater management controls, (2) hydrologic residence times, and (3) surface area of hydrologically connected features.
Source:
Effects of stormwater management and stream restoration on watershed nitrogen retention.
By: Newcomer Johnson, TA (Newcomer Johnson, Tamara A.); Kaushal, SS (Kaushal, Sujay S.); Mayer, PM (Mayer, Paul M.); Grese, MM (Grese, Melissa M.). BIOGEOCHEMISTRY, Volume: 121, Issue: 1, Pages: 81-106, Published: OCT 2014.

Greater connectivity to stream surface water may result in greater inputs of allochthonous nutrients that could stimulate internal nitrogen (N) and phosphorus (P) cycling in natural, restored, and created riparian wetlands. In conclusion, hydrologic connectivity to stream water increased allochthonous inputs that stimulated soil N and P cycling and that likely led to greater retention of sediment and nutrients in created and natural wetlands. Our findings suggest that wetland creation and restoration projects should be designed to allow connectivity with stream water if the goal is to optimize the function of water quality improvement in a watershed.
Source:
Hydrologic Connectivity to Streams Increases Nitrogen and Phosphorus Inputs and Cycling in Soils of Created and Natural Floodplain Wetlands.
By: Wolf, KL (Wolf, Kristin L.); Noe, GB (Noe, Gregory B.); Ahn, C (Ahn, Changwoo). JOURNAL OF ENVIRONMENTAL QUALITY, Volume: 42, Issue: 4, Pages: 1245-1255, Published: JUL-AUG 2013.

This paper presents an ecohydrological approach to the reduction in the phosphorus load transported by the Pilica River into a lowland reservoir in the central region of Poland. The research was carried out on a 26.6 ha section of the river floodplain where vegetation was the important component accumulating phosphorus (P) in plant tissues. In summer, the biological potential for phosphorus retention in the floodplain was estimated to be as high as 255kg P. However, this potential can be increased by planting fast-growing patches of willow. Therefore, covering 24% or 48% of the entire floodplain (identified by DTM analysis) where are suitable hydrological conditions for growth and cultivation of willows may increase this accumulation to 332 or 399 kg P, respectively. in the long run, an appropriate management strategy (cutting and removing the biomass from the floodplain) should favor a decrease in nutrient transport downstream. (C) 2007 Elsevier B.V. All rights reserved.
Source:
Quantification of phosphorus retention efficiency by floodplain vegetation and a management strategy for a eutrophic reservoir restoration.
By: iedrzynska, E (Kiedrzynska, Edyta) ; Wagner, I (Wagner, Iwona); Zalewski, M (Zalewski, Maciej), Volume: 33, Issue: 1, Pages: 15-25, Published: MAY 1 2008.

Most wetlands of the Mississippi deltaic plain are isolated from riverine input due to flood control levees along the Mississippi River. These levees have altered hydrology and ecology and are a primary cause of massive wetland loss in the delta. River water is being reintroduced into coastal basins as part of a large-scale ecological engineering effort to restore the delta. We quantified freshwater, nitrogen, and phosphorus inputs to the Breton Sound Estuary for three climatically different years (2000, 2001, and 2002). Water budgets included precipitation, potential evapotranspiration, the diversion, stormwater pumps, and ground-water. Precipitation contributed 48-57% of freshwater input, while

the diversion accounted for 33-48%. Net groundwater input accounted for less than 0.05% of freshwater inputs. Inputs of ammonium (NH4-N), nitrate (NO3-N), total nitrogen (TN), and total phosphorus (TP) were determined for each of the water sources. Atmospheric deposition was the most important input of NH4-N (57-62% or 1.44 x 10(5)-2.32 x 10(5) kg yr(-1)) followed by the diversion. The diversion was the greatest source of NO3-N (67-83%,7.78 x 10(5)-1.64 x 106 kg yr(-1) 1) and TN (60-71%). The diversion contributed 41-60% of TP input (1.17 x 10(5)-2.32 x 10(5) kg yr(-1)). Annual loading rates of NH4-N and NO3-N were 0.17-0.27 and 1.2-2.3 g N m(-2) yr(-1), respectively, for the total basin indicating strong retention of nitrogen in the basin. Nitrogen retention through denitrification and burial was estimated for the upper basin. (c) 2008 Elsevier B.V. All rights reserved.

Source:

The impacts of re-introducing Mississippi River water on the hydrologic budget and nutrient inputs of a deltaic estuary.

By: Hyfield, ECG (Hyfield, Emily C. G.); Day, JW (Day, John W.) ; Cable, JE (Cable, Jaye E.) ; Justic, D (Justic, Dubravko), Volume: 32, Issue: 4, Pages: 347-359, Published: APR 1 2008

Coastal regions in many regions of the world are under increasing pressure from the expansion of agriculture and urbanization associated with elevated N and P loading and eutrophication of coastal estuaries. I compared how mixed land use catchments deliver dissolved and particulate forms of C, N, and P in streamflow to the Swan-Canning estuary that bisects Perth, Western Australia. Dissolved organic carbon (DOC) and dissolved organic nitrogen (DON) composed the majority of the total C and N load, particulate C and N fluxes were minor, and P fluxes were evenly split between soluble reactive phosphorus and particulate/organic P. In contrast to current biogeochemical theory, DON export was dominant in urban and agricultural catchments in the low-gradient environment of the Swan Coastal Plain, whereas NO(3) export was a greater factor in higher-gradient, forested catchments on the urban fringe. This trend suggests that hydrologic conditions that supported coastal wetlands prior to human development may still promote DON mobilization as well as dissolved inorganic nitrogen loss along hydrologic flow paths. Substantial variability in export of C, N, and P across catchments highlights the unique hydrologic properties of Australian catchments. Areal C, N, and P export was significantly related to catchment runoff which was lowest in a catchment with inland drainage, but greatest in urban catchments with impervious surfaces and shallow groundwater. The effective delivery of DOC and DON to aquatic ecosystems in urbanizing coastal catchments underscores the importance of restoration efforts that address hydrologic retention as well as the source and bioavailability of dissolved organic matter.

Source:

Catchment export of carbon, nitrogen, and phosphorus across an agro-urban land use gradient, Swan-Canning River system, southwestern Australia.

By: Petrone, KC (Petrone, Kevin C.), Volume: 115, Article Number: G01016, DOI: 10.1029/2009JG001051, Published: MAR 27 2010

3.7. Groundwater retention & Riparian buffers

The interface found where rivers meet terrestrial systems is an ecotone that has a profound influence on the movement of water and waterborne contaminants. Maintaining or restoring ecotone functions and characteristics such as natural near stream vegetation and channel morphology are important means to safeguard water quality in agricultural landscapes. A riparian buffer zone of 20 to 30 m width can remove up to 100% of incoming nitrate. Denitrification is the major pathway of removal and rates depend on nitrate loadings, carbon availability, and hydrology. Denitrification occurs throughout the year as long as subsurface hydrology is intact, whereas plant uptake of nitrogen is limited to seasonal removal. Nitrate removal is favored in forested areas with subsurface flow and is less in grassed areas with surface flow. The balance between surface and subsurface flows and the redox conditions that

result are critical to nitrate removal in riparian ecotones. Surface retention of nutrients and sediment is a function of slope length and gradient, vegetation density, and flow rates. Plant communities play a major role in nitrogen cycling by acting as a source of carbon for denitrifying bacteria, direct uptake of nutrients, and creating oxidized rhizospheres where nitrification can occur. Restoration of riparian zones requires knowledge of the area's hydrology and ecology, as well as clear goals for the project. Restoration of riparian zones for water quality improvement may provide higher economic benefits than allocating the same land to crops. While it is possible to restore the functions of natural floodplain systems, existing restoration techniques are in their infancy and success cannot be guaranteed, especially given the extent of hydrological modification that has occurred in most developed countries.

Source:

The effectiveness and restoration potential of riparian ecotones for the management of nonpoint source pollution, particularly nitrate.

By: Fennessy, MS (Fennessy, MS); Cronk, JK (Cronk, JK), Volume: 27, Issue: 4, Pages: 285-317, Published: 1997

The problem of nitrogen pollution in European surface- and groundwaters has become a focus of recent European and Scandinavian directives, with legislation calling for a 50% reduction of N losses by the years 1995 and 2000, respectively. This paper provides a conceptual framework upon which management strategies to reduce losses of diffuse nitrogen pollution to surface waters may be based. The control of nitrogen pollution may take place through an increase in the complexity of the landscape, not throughout the catchment area, but rather in specific zones, the river corridor in particular. Within river corridors, riparian areas have been recognized globally for their value as nutrient removal ''buffer systems''. Studies have identified vegetation uptake and microbial denitrification as the primary mechanisms responsible for N removal in these systems. For these processes to function optimally on an annual basis, both vegetation and water regime must be managed. The establishment and management of riparian buffer zones in suitable places within river corridors, will provide a stable and sustainable water-protection function. This will complement future nitrogen input control strategies, needed for both the long-term protection of groundwater and surface waters in Europe as a whole, and for the proposed 50% reduction in nitrogen loading to the Baltic and North Sea coastal waters by the turn of the century.

Source:

NITROGEN-RETENTION IN RIVER CORRIDORS - EUROPEAN PERSPECTIVE.

By: HAYCOCK, NE (HAYCOCK, NE); PINAY, G (PINAY, G); WALKER, C (WALKER, C), Volume: 22, Issue: 6, Pages: 340-346, Published: OCT 1993

International meetings on ecological engineering, with a focus on riparian buffer zones, served as the source for selected papers in this special issue: (1) an International Workshop on Efficiency of Purification Processes in Riparian Buffer Zones: Their Design and Planning in Agricultural Watersheds, jointly organised by Hokkaido University, Japan, the National Agricultural Research Center for Hokkaido Region, Japan, Civil Engineering Research Institute of Hokkaido, Japan, and the Institute of Geography, University of Tartu, Estonia, and held from 5 to 9 November 2001 in Kushiro City, Hokkaido, Japan; and (2) an International Conference on Ecological Engineering for Landscape Services and Products, jointly organised by the International Ecological Engineering Society (IEES) and Lincoln University, Christchurch, New Zealand, and held from 25 to 29 November 2001 in Christchurch, New Zealand. At these two meetings, altogether 94 oral presentations (17 from invited speakers) and 15 posters by representatives from 21 countries were presented. The editorial paper highlights trends in investigation of the purification processes in riparian buffer zones as well as planning, design and management aspects of riparian buffersregarding the wide spectrum of their ecological functions; it characterises the two international meetings which served as sources for the selected papers and briefly explains the main aspects of these papers.

Source:
Purification processes, ecological functions, planning and design of riparian buffer zones in agricultural watersheds.
By: Mander, U (Mander, U); Kuusemets, V (Kuusemets, V); Hayakawa, Y (Hayakawa, Y), Volume: 24, Issue: 5, Pages: 421-432, Published: MAY 30 2005

The Valdivian rainforest ecoregion in Chile (35 degrees-48 degrees S) has a high conservation priority worldwide. These forests are also keys for social welfare as a result of their supply of timber as well as ecosystem services. Forests in the ecoregion have been extensively converted to fast growing Pinus radiata and Eucalyptus spp. plantations for timber production promoted by public policies and timber companies. This study describes the results of detailed measurements of hydrology and stream water chemistry in eight small watersheds in south central Chile, subjected to replacement of native temperate rainforest by exotic Eucalyptus plantations. In this system, watersheds have streamside buffers of native forest (SNFW) with varying widths. Results indicate that retention of SNFW counteracts hydrologic effects of Eucalyptus plantations, which are widely known to reduce water yields. A 1.4% rate of increase of the run-off coefficient for each metre of increase of SNFW was observed. In addition, a decrease in the concentrations of total nitrogen, dissolved inorganic nitrogen (DIN), nitrate-N, and different sized fractions of particulate organic matter were found in streams draining these plantations as a function of increasing SNFW. Streamside buffer widths of 17-22m for total nitrogen and DIN concentrations and 36m for sediments were required to provide comparable values to reference watersheds (100% native forest). The findings from this study suggest that SNFW may significantly reduce adverse effects from exotic species forestry plantations on water provision in an area of south central Chile where exotic forest plantations are rapidly expanding. Copyright (c) 2014 John Wiley & Sons, Ltd.
Source:
Buffer effects of streamside native forests on water provision in watersheds dominated by exotic forest plantations.
By: Little, C (Little, Christian); Cuevas, JG (Cuevas, Jaime G.) ; Lara, A (Lara, Antonio) ; Pino, M (Pino, Mario) ; Schoenholtz, S (Schoenholtz, Stephen)[7], Volume: 8, Issue: 7, Pages: 1205-1217, Published: OCT 2015

Buffer strips with no added fertilizers are a mitigation measure to reduce P loads from agricultural land to surface water. However, the experimental evidence on their effectiveness (BSE) has been from sloping locations with shallow flow and surface runoff. The aim of this experimental study was to quantify BSE for P on flat agricultural lowland, predominantly with deep flow. We selected sites characteristic of five major hydrogeological classes in the Netherlands and in each experimental field installed paired 5-m-wide unfertilized grass (BS) and reference treatments (REF) that abutted the ditch. The REF treatments were managed similar to the adjacent grass or maize field, but BS treatments were only harvested. Each treatment had a reservoir in the ditch to collect and measure discharge and flow-proportional P concentration for 3 or 4yr. We also measured net P withdrawal, the P status of the soil and P concentration in upper groundwater. We found a significant BSE for P of 61% on the site with the shallowest flow and steepest slope (2%). At the other sites, BSE was low and statistically insignificant. We conclude that harvested unfertilized buffer strips reduce P loads from flat fields only in specific areas with high surface runoff and/or shallow flow, especially in combination with a high original soil P status.
Source:
Effectiveness of buffer strips without added fertilizer to reduce phosphorus loads from flat fields to surface waters.
By: Noij, IGAM (Noij, I. G. A. M.); Heinen, M (Heinen, M.); Heesmans, HIM (Heesmans, H. I. M.); Thissen, JTNM (Thissen, J. T. N. M.); Groenendijk, P (Groenendijk, P.), Volume: 29, Pages: 162-174, Published: MAR 2013

3.8. Aquifer retention & Wetlands

This study aims to investigate the physical and chemical effects of interactions between groundwater and surface water (GW-SW)-particularly in streams-on nitrate contamination. The effects of GW-SW interactions are briefly reviewed, with a particular emphasis on processes and environments that influence increases or decreases in nitrate concentration. Then, this paper analyses nitrate concentrations in groundwater and surface water in the western Po plain (Northwestern Italy); this analysis includes the nitrate concentration profiles across the shallow aquifer and intersecting the main streams on the plain. The investigation highlights how the concentration trends are similar, even when nitrate levels in rivers and groundwater are not comparable. The maximum nitrate concentrations in the surface water were generally measured in areas with high-nitrate levels in groundwater. An analysis of the nitrate concentration profiles highlighted the mutual influences of GW-SW. The most important streams on the plain (the Po River and Stura di Demonte River), both of them gaining streams, seem to reduce the nitrate concentrations of groundwater at a study scale. The proposed conceptual model indicates how the near-stream environment (the riparian zone, wetlands, hyporheic zone and shallow organic-rich soils in the near-stream environment) and the groundwater flow systems in shallow and deep aquifers, from the recharge zone to the streams, could dramatically affect the nitrate concentrations.

Source:

Nitrate contamination of groundwater in the western Po Plain (Italy): the effects of groundwater and surface water interactions.

By: asagna, M (Lasagna, Manuela) ; De Luca, DA (De Luca, Domenico Antonio) ; Franchino, E (Franchino, Elisa), Volume: 75, Issue: 3

Article Number: 240, Published: FEB 2016

Peatlands are complex ecosystems driven by many physical, chemical, and biological processes. Peat soils have a significant impact on water quality, ecosystem productivity and greenhouse gas emissions. However, the extent of peatlands is decreasing across the world, mainly because of anthropogenic activities such as drainage for agriculture or groundwater abstractions in underlying aquifers. Potential changes in precipitation and temperature in the future are likely to apply additional pressure to wetland. In this context, a methodology for assessing and comparing the respective impacts of groundwater abstraction and climate change on a groundwater-fed wetland (135 km(2)) located in Northwest France, is presented. A groundwater model was developed, using flexible boundary conditions to represent surface-subsurface interactions which allowed examination of the extent of the wetland areas. This variable parameter is highly important for land management and is usually not considered in impact studies. The model was coupled with recharge estimation, groundwater abstraction scenarios, and climate change scenarios downscaled from 14 GCMs corresponding to the A1B greenhouse gas (GHG) scenario over the periods 1961-2000 and 2081-2100. Results show that climate change is expected to have an important impact and reduce the surface of wetlands by 5.3-13.6%. In comparison, the impact of groundwater abstraction (100% increase in the expected scenarios) would lead to a maximum decrease of 3.7%. Results also show that the impacts of climate change and groundwater abstraction could be partially mitigated by decreasing or stopping land drainage in specific parts of the area. Water management will require an appropriate compromise which encompasses ecosystem preservation, economic and public domain activities.

Source:

Investigating the respective impacts of groundwater exploitation and climate change on wetland extension over 150 years.

By: Landes, AAL (Landes, Antoine Armandine Les); Aquilina, L (Aquilina, Luc); De Ridder, J (De Ridder, Jo); Longuevergne, L (Longuevergne, Laurent); Page, C (Page, Christian); Goderniaux, P (Goderniaux, Pascal), Volume: 509, Pages: 367-378, Published: FEB 13 2014

The Spreewald wetland is a large, peaty, inland delta wetland in which the water level is managed by weirs in cascade belts across an extensive, partly channelized running water system. To model the quality of the water, 946 surface water samples from 43 sites were analyzed for 29 water quality parameters in two monitoring programs spanning a period of six years. In this study, we pursued a multivariate approach using nonlinear principal component analysis (Isomap) to identify the prevailing processes that control the water quality of the complex surface water system.

The first four principal components explained 79% of the variance in the dataset These components were interpreted as anthropogenic impact factors, such as groundwater exfiltration from degraded peat areas and the influence of coal mining drainage with respect to SO4, as well as groundwater exfiltration from mineral aquifers, and phytoplankton growth and competition. A sub-area of the Spreewald wetland, characterized by a sandy aquifer overlain by degraded peat, had the greatest impact on downstream surface water quality for most of the investigated parameters. In order to achieve better water quality in the Spreewald wetland, pollutant input - particularly SO4 input from the tributaries - must be controlled by enhancing the wetland's buffer capacity in the catchment, and peat mineralization and groundwater exfiltration must be minimized by raising the water table of the peatland area and receiving waters.
The results show that Isomap is a very powerful tool for gaining a better insight into the dominating processes defining the surface water quality of complex wetland systems. Nevertheless, to be able to draw the right conclusions from multivariate statistical approaches such as Isomap it is necessary to possess basic knowledge of the structure of the system and of the processes that may occur. (C) 2012 Elsevier B.V. All rights reserved.
Source:
Screening of prevailing processes that drive surface water quality of running waters in a cultivated wetland region of Germany - A multivariate approach
By: Maassen, S (Maassen, Sebastian); Balla, D (Balla, Dagmar); Kalettka, T (Kalettka, Thomas); Gabriel, O (Gabriel, Oliver), Volume: 438, Pages: 154-165, Published: NOV 1 2012

The relative influences of hydrologic processes and biogeochemistry on the transport and retention of minor solutes were compared in the riverbed of the lower Merced River (California, USA). The subsurface of this reach receives ground water discharge and surface water infiltration due to an altered hydraulic setting resulting from agricultural irrigation. Filtered ground water samples were collected from 30 drive point locations in March, June, and October 2004. Hydrologic processes, described previously, were verified by observations of bromine concentrations; manganese was used to indicate redox conditions. The separate responses of the minor solutes strontium, barium, uranium, and phosphorus to these influences were examined. Correlation and principal component analyses indicate that hydrologic processes dominate the distribution of trace elements in the ground water. Redox conditions appear to be independent of hydrologic processes and account for most of the remaining data variability. With some variability, major processes are consistent in two sampling transects separated by 100 m.
Source:
Hydrologic and Biogeochemical Controls of River Subsurface Solutes under Agriculturally Enhanced Ground Water Flow
By: Wildman, RA (Wildman, Richard A., Jr.)[1] ; Domagalski, JL (Domagalski, Joseph L.)[2] ; Hering, JG (Hering, Janet G.), Volume: 38, Issue: 5, Pages: 1830-1840, Published: SEP-OCT 2009

Nitrate concentrations in groundwater decreased significantly along groundwater flow paths crossing the riparian zones. Mixing of nitrate-rich groundwater with nitrate-poor river water accounted for most of the change in nitrate concentration along groundwater flow paths. The fraction of river water in wells increased from the margin of the floodplain with an alluvial terrace (31% river water) to the river; an average of 80% river water occured in the natural riparian forest. However, observed concentrations of nitrate were always less than or equal to the concentration expected from mixing alone, indicating biological effects. Denitrification rates were low or 0 below the depth of the water table in all seasons, suggesting that denitrification was not an important nitrate sink. The remaining change in nitrate concentration not accounted for by mixing was likely the result of vegetation uptake and soil microbial immobilization. Indeed, the largest decrease in nitrate concentration (70 mu g N L-1 m(-1) of groundwater flow) along a groundwater flow path was measured under the natural riparian forest during the growing season.

Because mixing is not a retention process, nitrogen retention in large river margins can be highly over-estimated if the importance of mixing between groundwater and river water is not accounted for. Nonetheless, our results confirm that the effort to reduce non-point-source pollution should be concentrated on wetlands and vegetated riparian zones along small streams.

Source:

Change in groundwater nitrate concentration in a large river floodplain: denitrification, uptake, or mixing?

By: Pinay, G (Pinay, G); Ruffinoni, C (Ruffinoni, C); Wondzell, S (Wondzell, S); Gazelle, F (Gazelle, F), Volume: 17, Issue: 2, Pages: 179-189, Published: JUN 1998

3.9. Landscape retention & Biofiltration

Bioretention is a well-established tool to reduce nutrient transport from impervious urban landscapes to sensitive riparian habitat in mesic climates. However, the effectiveness of bioretention is less tested in arid and semi-arid climates. Nutrient retention performance was evaluated in three 10 m(2) bioretention cells with different vegetation communities: (I) an irrigated wetland vegetation community, (2) an un-irrigated upland vegetation community, and (3) a no-vegetation control. Synthetic stormwater was added to each cell to simulate the average annual runoff of precipitation from a 220 m(2) impervious surface in Salt Lake City, UT. A significant amount of phosphate (approximate to 50%) was retained by all treatments during the 12-month study. However, total nitrogen (TN) retention was only achieved in the Wetland and Upland treatments (59% and 22%, respectively), and nitrate retention was only achieved in the Wetland treatment (38%). In contrast, the Upland and Control treatments exported 2 and 9 times more nitrate than was added in the simulated rainfall events. Improved nitrogen retention by the Wetland treatment came at the cost of over 12,000l (3200 gal) of irrigation to sustain the vegetation through the hot, dry summer. We hypothesize that plant uptake and soil microbial communities are driving nutrient retention in bioretention systems, and that increasing net primary production will increase nutrient retention. In water-limited climates, this can be sustainably achieved by either: increasing native upland vegetation densities above naturally expected densities, or, by using gray water instead of municipal water sources to irrigate wetland communities through dry summer periods.

Source:

Evaluation of three vegetation treatments in bioretention gardens in a semi-arid climate

By: Houdeshel, CD (Houdeshel, C. Dasch); Hultine, KR (Hultine, Kevin R.); Johnson, NC (Johnson, Nancy Collins); Porneroy, CA (Porneroy, Christine A.), LANDSCAPE AND URBAN PLANNING, Volume: 135, Pages: 62-72, Published: MAR 2015

Urbanization leads to water catchments becoming more impervious and channelized. These modifications to the natural landscape result in reduced water infiltration into soils and base flow components that cause a greater volume and rate of surface water runoff. In contrast to conventional stormwater management systems, water-sensitive urban design (WSUD) technologies manage rainfall where it falls, through enhancement of infiltration capacity of impervious areas and rerouting runoff across pervious areas. WSUD aims to better incorporate several urban water sources, including stormwater, into the local hydrological cycle so as to (1) reduce demand on potable water, (2) minimize pollutant loading to surface waters, and (3) restore or maintain predevelopment hydrological processes. Bioretention systems are designed to remove both dissolved pollutants and particulate matter from stormwater runoff and reduce the volume and rate of stormwater discharged. Treatment is achieved via a number of chemical, biological and physical processes including sedimentation, filtration, sorption, reduction, vegetative uptake and microbial biomass assimilation. The efficiency of bioretention systems in the treatment of contaminants in stormwater depends on a number of factors including substrate conditions, type of vegetation, climatic conditions and on the volume and rate of stormwater infiltrated and discharged. This chapter discusses the various processes involved in the treatment of stormwater within bioretention systems; in particular, the fate of nutrients such as nitrogen and phosphorus, and metals, and the soil plant processes involved in their retention. The factors affecting treatment efficiency are also examined.

Source:
The Role of Bioretention Systems in the Treatment of Stormwater.
By: Laurenson, G (Laurenson, Georgina); Laurenson, S (Laurenson, Seth); Bolan, N (Bolan, Nanthi); Beecham, S (Beecham, Simon); Clark, I (Clark, Ian), ADVANCES IN AGRONOMY, VOL 120, Book Series: Advances in Agronomy, Volume: 120, Pages: 223-274, Published: 2013

3.10. Landscape retention & Polders

One of the possible ways of protection of a built up area against floods is to build dry flood pools in or above the endangered areas. The utilization of natural landscape helps to effectively define the flood pool locations with minimal interference with the landscape. Bolatice municipality, where a system of polders is built in its cadastre, serves as an example of this way of dealing with flood protection. This article presents a suggestion to build a new polder, which complements the current protective function of the existing system of dry reservoirs in this municipality. Its retention capability puts it among the larger Bolatice dry reservoirs. The hydro-technical calculations, which support the designed polders, reflect the flow capacity of the Opusta stream-bed, into which the other polders in Bolatice municipality cadastre are drained. The designed polder also helps to protect municipalities located below Bolatice against the flood wave, including the industrial area and the system of ponds.

Source:
THE SOLUTION OF FLOOD PROTECTION USING A SYSTEM OF POLDERS IN THE MUNICIPALITY CADASTER.
By: Gola, L (Gola, Lukas); Vaclavik, V (Vaclavik, Vojtech); Dvorsky, T (Dvorsky, Tomas); Valicek, J (Valicek, Jan); Coufal, M (Coufal, Marek), WATER RESOURCES, FOREST, MARINE AND OCEAN ECOSYSTEMS, SGEM 2015, VOL I, Book Series: International Multidisciplinary Scientific GeoConference-SGEM, Pages: 705-712, Published: 2015

Dry polders were observed in the Silesian village Bolatice. Integrated fully functional system of flood protection is implemented around the village. Runoffs from the watersheds of tanks were calculated with disign precipitation in scope of retention of water in the agricultural landscape. Average annual values of loss of soil were calculated on the selected slopes of polders for evaluating the intensity of water erosion. Model areas, for example meadows or fields with diverse crop cultivation, were used in this work. At the end the functions of dry polders are evaluated.

Source:
UTILIZATING DRY POLDER AS FLOOD MEASURES IN AGRICULTURAL LANDSCAPE.
By: Novakova, J (Novakova, Jana); Dospivova, P (Dospivova, Petra); Melcakova, I (Melcakova, Iva), GEOCONFERENCE ON WATER RESOURCES, FOREST, MARINE AND OCEAN ECOSYSTEMS, VOL I (SGEM 2014), Book Series: International Multidisciplinary Scientific GeoConference-SGEM, Pages: 823-828, Published: 2014

Multivariate analysis of macroinvertebrates in urban water systems (mainly drainage ditches and ponds) in polder areas of the Rhine-Meuse river district in the Netherlands revealed that nutrients, sediment composition, transparency and habitat structure are key factors for macroinvertebrate diversity. Habitat structure was provided by aquatic macrophytes with highly structured growth forms (such as peplids. elodeids and magnonymphaeids). Occurrence and abundance of these plants were subsequently related to nutrient load. Nitrate levels in surface water were negatively related to several diversity indices of macroinvertebrate assemblages and submerged vegetation cover was positively related to diversity indices.
Proofing cities for climate change could enhance ecological status of urban waters by implementing measures to decrease local nutrient input from rain storms (e.g. by increase of infiltrating capacity) and upward seepage of nutrient-rich groundwater originating from the rivers Rhine and Meuse. Additionally, when creating water storage ponds and drainage ditches or increasing storage capacity of urban water bodies, attention could also be paid to the construction of natural banks to stimulate vegetation development and to increase suitable habitat for macroinvertebrate species. (C) 2011 Elsevier B.V. All rights reserved.
Source:
Key factors for biodiversity of surface waters in climate proof cities
By: Vermonden, K (Vermonden, Kim); van der Velde, G (van der Velde, Gerard); Leuven, RSEW (Leuven, Rob S. E. W.), RESOURCES CONSERVATION AND RECYCLING, Volume: 64, Pages: 56-62, Special Issue: SI, Published: JUL 2012

3.11. Landscape retention and ponds

Although well-known ecological patterns apply to most ponds in Europe and elsewhere, recent data highlight that part of the environmental variables governing pond biodiversity remain specific to climatic/biogeographic regions and to elevation ranges, suggesting that, in addition to common practice, management plans should include range-specific measures.

- Beyond the contribution of individual ponds to the aquatic and terrestrial life, connected networks of ponds are vital in the provision of new climate space as a response to global climate change, by allowing the observed northward and/or upward movements of species.
- In terms of services, ponds offer sustainable solutions to key issues of water management and climate change such as nutrient retention, rainfall interception, or carbon sequestration.
- While the ecological role of ponds is now well-established, authoritative research-based advice remains needed to inform future direction in the conservation of small water bodies and to further bridge the gap between science and practice.
- Species–area relationships, habitat heterogeneity, and surrounding environments are well-known key drivers for local pond diversity. Jeliazkov et al. (2013) emphasize, however, that species richness significantly increases with pond density from local to regional levels. In landscapes experiencing rapid environmental changes, ponds indeed provide vital stepping stones that are essential for the migration, dispersal, and genetic exchange of wild species, including those species which range over large areas (birds and mammals) but require ponds as part of the mosaic of wetland habitats they exploit. Where pond density has declined,

replacement through pond creation could also restore previously fragmented wetland landscapes (Dalbeck & Weinberg, 2009).

- While the difference between large ponds and small lakes is often debated (Oertli et al., 2005), Hamerlik et al. (2013) report an interesting ecological threshold separating alpine pond and lake systems, where, at a surface area of 2 ha, the species-area pattern changes significantly (alpha diversity was not related to area for water bodies below 2 ha, but was positively correlated with area in larger systems). The significant effects of incoming detritus and incident light upon pond community diversity, however, reveal that changes in local environments (e.g., the conversion of forest to cropping systems) strongly influence food webs in small water bodies (Dézerald et al., 2013). The set of environmental variables governing pond biodiversity (both in terms of community composition and species traits) is to some extent specific to climatic/biogeographic regions (Ruhí et al., 2013; de Marco et al., 2013; see also Céréghino et al., 2012) and to elevation ranges (Ilg & Oertli, 2013). Therefore, although biological diversity could be favoured by a common set of pond management practices, data point toward the idea that management plans should include elevation- and/or region-specific measures.
- Life histories, dispersal patterns, and biological interactions (notably the trophic ones) also play major roles in determining pond biodiversity (Blaustein et al., 2013). Life history patterns enable many temporally segregated populations to utilize small ecosystems by reducing competition for space and habitat resources (de Andrade et al., 2013; see also Cayrou & Céréghino, 2005). Colonization dynamics strongly influence within and among population genetic variation and evolutionary potential of populations (Ortells et al., 2013), and more specifically, predators play a key role in generating patterns of food web topology across regional environments (Dézerald et al., 2013). Like other freshwater (and terrestrial) habitat types, ponds are subjected to species introductions (Rodriguez-Perez et al., 2013). Species richness typically decreases when fish are present (Ruggiero et al., 2008). Many fish species are predators to macroinvertebrates, while those species introduced to serve anthropogenic purposes (e.g., mosquitofish) can cause substantial injuries to large numbers of larval amphibians in a wetland (Shulse & Semlitsch, 2013). Other introduced species like crayfish or mute swans are likely to impact either native species (e.g., amphibians) and habitat structure (e.g., macrophyte beds; Gayet et al., 2013), but the extent of adverse impacts generated by these species appears to be density-dependent.
- Although ponds are small wetland features, they may be regarded as key components of wider landscapes. Compared to other surface waters, ponds still receive little effective protection from legislation or policy. More specifically, despite much interest in the management of catchments, protection of ponds through landscape scale protection measures is rarely achieved. In this context, the Important Areas for Ponds (IAP) concept proposed and developed by Pond Conservation in the UK (Pond Conservation, 2007) and the European Pond Conservation Network may serve as a relevant scheme (see an outline at http://campus.hesge.ch/epcn/projects_propond.asp). IAPs are conceptually similar to the Important Bird Areas (IBAs proposed by Birdlife International) and the Important Plant Areas (IPAs by Plantlife International). Owing to the wide distribution of ponds, IAPs concern large areas of the landscape, thereby calling for landscape level management plans.
- The ecological role and more generally the value of ponds in our landscapes are better established than a few years ago. In light of expected economic development, authoritative

research-based advice is now needed to inform future direction in the conservation of small water bodies. Initiatives such as the European Pond Conservation Network play such a role by bringing together scientists, practitioners, and policy makers. To date, most ongoing projects led by EPCN members clearly aim at strengthening our understanding of pond biodiversity, ecosystem services, and the links between these two aspects. Hence, we may expect a flourish of relevant information to come and, hopefully, the 6th EPCN conference to be held in September 2014 in Huesca (Spain) should provide opportunities to learn more about pond ecology, and will certainly further contribute to bridge the gap between science and practice.

Céréghino, R., Boix, D., Cauchie, HM. et al. **The ecological role of ponds in a changing world.** Hydrobiologia (2014) 723: 1. doi:10.1007/s10750-013-1719-y

Climate change is predicted to cause more extreme rain fall in Europe. In case of insufficient retention capacity of sewers, urban storm water needs to be disconnected from the sewer systems to avoid sewage overflows. Moreover, the storage and discharge capacity of surface water systems in urban areas must be increased to manage larger volumes of storm water and to prevent flooding.

- Proofing cities for climate change by reconstruction of water systems not only helps to avoid 'wet feet', but also offers promising possibilities to create aquatic habitats, to improve water quality and to optimize biodiversity values of urban areas. For that purpose knowledge is needed on key factors determining the ecological status of urban drainage systems.
- Multivariate analysis of macroinvertebrates in urban water systems (mainly drainage ditches and ponds) in polder areas of the Rhine–Meuse river district in the Netherlands revealed that nutrients, sediment composition, transparency and habitat structure are key factors for macroinvertebrate diversity. Habitat structure was provided by aquatic macrophytes with highly structured growth forms (such as peplids, elodeids and magnonymphaeids). Occurrence and abundance of these plants were subsequently related to nutrient load. Nitrate levels in surface water were negatively related to several diversity indices of macroinvertebrate assemblages and submerged vegetation cover was positively related to diversity indices.
- Knowing the key factors for biodiversity in urban water systems, we investigated the sources of nutrient load. The primary source was the local upward seepage from river water. Next to upward seepage, water quality was also negatively influenced by storm water run off after an intense rain storm. So, higher river discharges and extreme rainfall deteriorate water quality and indirectly affect biodiversity in urban water systems.
- Proofing cities for climate change could enhance ecological status of urban waters by implementing measures to decrease local nutrient input from rain storms (e.g. by increase of infiltrating capacity) and upward seepage of nutrient-rich groundwater originating from the rivers Rhine and Meuse. Additionally, when creating water storage ponds and drainage ditches or increasing storage capacity of urban water bodies, attention could also be paid to the construction of natural banks to stimulate vegetation development and to increase suitable habitat for macroinvertebrate species.

Kim Vermonden, Gerard van der Velde, Rob S.E.W. Leuven, Key factors for biodiversity of surface waters in climate proof cities, Resources, Conservation and Recycling, Volume 64, July 2012, Pages 56-62, ISSN 0921-3449, http://dx.doi.org/10.1016/j.resconrec.2011.01.003.

Stormwater ponds are a common feature of the urban landscape in many countries with advanced stormwater management. Built to control the impacts of urbanization in the form of increased runoff flows, volumes and pollution loads, stormwater ponds are exposed to strong anthropogenic pressures.

- In the fundamental research field, this approach intends to gain knowledge on: (1) oligochaete species ecology and sensitivity to contaminants, and (2) the toxic effects of specific and/or multiple contaminants in water and sediment.
- In the research and development field, we seek to improve the application and efficiency of methodologies with respect to stormwater ponds by adopting a gradient analysis approach for: (1) testing the oligochaete methodology and associated hypotheses developed from previous research (relevance of oligochaetes in ERA of stormwater ponds), (2) improving the indicators of sediment functioning processes (nutrient cycling) based on species functional traits, structure and composition of oligochaete communities, to define SPP objectives, and (3) improving the indicators of sediment pollution based on species pollution sensitivity, structure and composition of the oligochaete communities for the BPP objectives.

Guillaume Tixier, Michel Lafont, Lee Grapentine, Quintin Rochfort, Jiri Marsalek, **Ecological risk assessment of urban stormwater ponds: Literature review and proposal of a new conceptual approach providing ecological quality goals and the associated bioassessment tools**, Ecological Indicators, Volume 11, Issue 6, November 2011, Pages 1497-1506, ISSN 1470-160X, http://dx.doi.org/10.1016/j.ecolind.2011.03.027.

Ponds were ubiquitous features of the traditional rural waterscape ….Using the result of a water quality survey at the entrance and the outlet of a small pond receiving agricultural drainage water, the Seneque/Riverstrahler biogeochemical model.

- In biogeochemical model results show 50% reduction in nitrogen fluxes crossing a pond.
- We show, 5% of the area of a basin devoted to ponds could reduce the riverine nitrogen export by up to 30%.

Source: Paul Passy, Josette Garnier, Gilles Billen, Corinne Fesneau, Julien Tournebize, **Restoration of ponds in rural landscapes: Modelling the effect on nitrate contamination of surface water (the Seine River Basin, France)**, Science of The Total Environment, Volume 430, 15 July 2012, Pages 280-290, ISSN 0048-9697, http://dx.doi.org/10.1016/j.scitotenv.2012.04.035.

- Stormwater management ponds have become a common Best Management Practice in urban and suburban landscapes.
- Stormwater ponds are designed to retain sediment-associated pollutants that are picked up during runoff events so those pollutants are not flushed to natural receiving waters.
- In addition, these ponds are often occupied by aquatic and semi-aquatic species in developing watersheds, where persisting natural wetlands may be sparse and/or degraded themselves.
- Data presented here show that toxicity thresholds for trace metals and PAHs in sediment and Cl- in the water column are routinely exceeded in the majority of stormwater ponds in this watershed.
- Moreover, while these pollutants separately may exert toxic pressure on organisms inhabiting stormwater ponds, in concert they, along with other pollutants not included here (e.g. PCBs), present the opportunity for various synergistic and/or antagonistic effects not accounted for in freshwater system pollutant guidelines. Therefore, our results clearly indicate the need for further investigation of the toxicity of stormwater pond sediments and water to semi-aquatic and aquatic wildlife and the resources they depend on.

- We recommend future research incorporates whole sediment exposures and characterization, as well as experiments investigating interactions between individual pollutants, specifically metals and salts.

Source: Gallagher, M.T., Snodgrass, J.W., Ownby, D.R. et al. **Watershed-scale analysis of pollutant distributions in stormwater management ponds.** Urban Ecosyst (2011) 14: 469. doi:10.1007/s11252-011-0162-y

Restoring urban infrastructure and managing the nitrogen cycle represent emerging challenges for urban water quality. We investigated whether **stormwater control measures (SCMs)**, a form of green infrastructure, integrated into restored and degraded urban stream networks can influence watershed nitrogen loads. We hypothesized that hydrologically connected floodplains and SCMs are **"hot spots"** for nitrogen removal through denitrification because they have ample organic carbon, low dissolved oxygen levels, and extended hydrologic residence times. We tested this hypothesis by comparing nitrogen retention metrics in two urban stream networks (one restored and one urban degraded) that each contain SCMs, and a forested reference watershed at the Baltimore Long-Term Ecological Research site. We used an urban watershed continuum approach which included sampling over both space and time with a combination of: (1) longitudinal reach-scale mass balances of nitrogen and carbon conducted over 2 years during baseflow and storms (n = 24 sampling dates × 15 stream reaches = 360) and (2) 15N push–pull tracer experiments to measure in situ denitrification in SCMs and floodplain features (n = 72). The SCMs consisted of inline wetlands installed below a storm drain outfall at one urban site (restored Spring Branch) and a wetland/wet pond configured in an oxbow design to receive water during high flow events at another highly urbanized site (Gwynns Run).

- The SCMs significantly decreased total **dissolved nitrogen (TDN)** concentrations at both sites and significantly increased dissolved organic carbon concentrations at one site. At Spring Branch, TDN retention estimated by mass balance (g/day) was ~150 times higher within the stream network than the SCMs.
- There were no significant differences between mean in situ denitrification rates between SCMs and hydrologically connected floodplains. Longitudinal N budgets along the stream network showed that hydrologically connected floodplains were important sites for watershed nitrogen retention due to groundwater–surface water interactions.
- Overall, our results indicate that hydrologic variability can influence nitrogen source/sink dynamics along engineered stream networks.
- Our analysis also suggests that **some major predictors for watershed N retention** were: (1) streamwater and groundwater flux through stream restoration or stormwater management controls, (2) hydrologic residence times, and (3) surface area of hydrologically connected features.

Source: Newcomer Johnson, T.A., Kaushal, S.S., Mayer, P.M. et al. Effects of stormwater management and stream restoration on watershed nitrogen retention. Biogeochemistry (2014) 121: 81. doi:10.1007/s10533-014-9999-5

To assess the relative contribution of stormwater ponds to the persistence of amphibian populations in suburban landscapes, we compared amphibian use of stormwater ponds and other available wetlands in suburban and forested watersheds. We surveyed three suburban and three primarily forested first-order watersheds to identify all potential wetlands that might serve as breeding sites for pond-breeding amphibians.

- Our goal was to determine whether stormwater ponds act as ecological traps in developed areas and evaluate the importance of natural and anthropogenic breeding habitats to suburban amphibian populations.

- We performed call, egg-mass, and larval surveys to measure breeding effort at each wetland in spring and summer 2007 and 2008. In suburban watersheds most (89%) of the wetlands that had breeding activity were either stormwater ponds or otherwise artificial. This pattern was also evident in the forested watersheds, where amphibians were primarily found breeding in wetlands created by past human activity.
- Late-stage larvae were found only in anthropogenic wetlands in all study areas because the remaining natural wetlands did not hold water long enough for larvae to complete development.
- Our results suggest that in urban and suburban landscapes with naturally low densities of wetlands, wetlands created by current or historic land uses may be as important to amphibian conservation as natural wetlands or pools and that management strategies directed at urban and suburban landscapes should recognize and incorporate human-created wetlands.

BRAND, A. B. and SNODGRASS, J. W. (2010), Value of Artificial Habitats for Amphibian Reproduction in Altered Landscapes. Conservation Biology, 24: 295–301. doi:10.1111/j.1523-1739.2009.01301.x

3.12. Floodplain restoration and nutrient retention

The water quality response to implementation of conservation measures across watersheds has been slower and smaller than expected. This has led many to question the efficacy of these measures and to call for stricter land and nutrient management strategies. In many cases, this limited response has been due to the legacies of past management activities, where sinks and stores of P along the land–freshwater continuum mask the effects of reductions in edge-of-field losses of P.

- The legacies of previous management and the remobilization of P stored in land, river, and lake systems are clearly important issues. Because of the lag time between BMP implementation and water quality improvements, remedial strategies should consider the time necessary for requilibration of watersheds and water bodies, where nutrient sinks may become sources of P with only slight changes in watershed management and hydrologic response.
- Clearly, hotspots of P accumulation and legacy across watersheds are subject to complex interactions of hydraulics, hydrology, geomorphology, and land management. It will take time to address the P legacy at the field or headwater scale to "cascade" and "spiral" down to the larger watershed scale.
- The lags in water-quality response to BMP implementation at the downstream watershed scale will be determined by the key rate-limiting (slowest responding) parts of the system. Furthermore, environmental change (e.g., impacts of climate change on C cycles and hydrology) will have important implications for recovery, because of shifting baselines in hydrologic response, for instance.
- A better understanding of the spatial and temporal aspects of watershed response to nutrient load reductions in both flowing and standing water bodies is needed, as well as an understanding of the scale at which responses may occur in a more timely fashion. It is likely that local water quality and quantity benefits may become evident more quickly at a smaller subwatershed scale. This is an important outcome in itself to help demonstrate change and foster accountability and ultimately wider adoption of conservation practices.
- As shown in the Coastal Plain poultry litter experiments, however, even at smaller scales, improvements at the field level may not immediately translate to the subwatershed.

- It is also important to accept in any watershed-P loss reduction strategy that it is essential to address the overall physical and social complexity of individual systems and the mitigation of non-agricultural sources of P. Only this will bring about lasting improvements in water quality as evidenced under all hydrologic (storm and non-storm) conditions.

Sharpley, A., H. P. Jarvie, A. Buda, L. May, B. Spears, and P. Kleinman. 2013. **Phosphorus Legacy: Overcoming the Effects of Past Management Practices to Mitigate Future Water Quality Impairment.** J. Environ. Qual. 42:1308-1326. doi:10.2134/jeq2013.03.0098

This paper presents an application of an indirect method, the alternative or replacement cost method to value a regulatory ecosystem service: the retention of river nutrient loads by floodplain wetlands. The paper presents a cost-minimisation model for nutrient abatement measures for the River Elbe. The model is applied to estimate the shadow price of phosphate and nitrogen nutrient retention services by restored floodplains.

- Development of a cost-minimisation model for nutrient abatement for the Elbe River Basin.
- Estimation of the shadow price of phosphate and nitrogen nutrient retention ecosystem services of restored floodplains.
- Strategic assessment of potential restoration sites demonstrates that nutrient retention benefits may offset costs.
- the shadow price or nutrient retention benefit of restored floodplain area increases with increasing nutrient load reduction targets.
- Scope effects have a smaller impact, but marginal benefits decrease with increasing scope of the floodplain restoration projects. The findings underline the fact that value estimates for regulatory ecosystem services are highly dependent on the contextual conditions of the service benefit area, such as the availability of substitute abatement options and abatement targets.
- We also conclude that the existence of clearly defined policy targets, such as for phosphate and nitrogen load reductions to the sea, in principle enhance the applicability of the replacement cost method. Implementing the replacement or alternative cost method is not difficult in concept, although detailed empirical analysis requires considerable effort.
- The process of imputing shadow prices that takes the various interdependencies in a river basin context into account is best addressed within the framework of optimisation models.

Malte Grossmann, **Economic value of the nutrient retention function of restored floodplain wetlands in the Elbe River basin**, Ecological Economics, Volume 83, November 2012, Pages 108-117, ISSN 0921-8009, http://dx.doi.org/10.1016/j.ecolecon.2012.03.008.

Water exchange, flow patterns and deposition of sediment and phosphorus were measured in cross-sections of a naturally functioning floodplain during one winter and in three restored floodplains following remeandering of formerly straightened and channelized rivers. Sediment and phosphorus depositional processes were studied, deploying artificial grass mats at different distances from the river channel. In addition, a mass-balance approach was applied on the experimental site.

- Allowing a watercourse to locally inundate its floodplain reduces the risk of flooding further downstream where the consequences can be more severe due to the increased size of the watercourse and the magnitude of discharge.
- In addition, the inundated areas can help store sediment, P and contaminants through depositional processes on the floodplain. Thus, river restoration in the way of remeandering of the river channel can remedy some of the consequences caused by former channelization

and deepening of the watercourse by helping to reduce P-loading to downstream water bodies and to restore important habitats. The experience gathered from Danish river and floodplain systems clearly support this hypothesis based on our measurements of a high deposition of sediment (3.0–6.57 kg DW m−2) and particulate P (1.2–7.3 g P m−2) on one naturally functioning and three restored rivers and floodplains.

- Impact assessment of restoration projects and research studies have increased our knowledge of the importance of flooding in lowland river systems for water, sediment and nutrient exchange and retention processes between the watercourse and the surrounding riparian areas.
- Future investigations of the interactions between rivers and floodplains should include more detailed measurements of water exchanges, residence times and sedimentation patterns in order to be able to calibrate and validate hydrodynamic models.

Sources: Kronvang, B. et al. **Water Exchange and Deposition of Sediment and Phosphorus during Inundation of Natural and Restored Lowland Floodplains**. Water, Air, and Soil Pollution 181, 115–121 (2007).

This paper presents an ecohydrological approach to the reduction in the phosphorus load transported by the Pilica River into a lowland reservoir in the central region of Poland. The research was carried out on a 26.6 ha section of the river floodplain where vegetation was the important component accumulating phosphorus (P) in plant tissues. Quantification of P accumulation in plant tissues and retention efficiency by plant communities in the floodplain were analyzed in order to develop a vegetation management strategy that would enhance river self-purification.

- Hydro-chemical characteristics of groundwater changed over the growing season. The greatest dynamic was observed at the study sites with P. australis where concentrations of SRP reached their highest values in spring (2.43 mg dm−3) and decreased in summer and autumn (0.04 mg dm−3).
- The phosphorus content in plant tissues diminished from spring, ranging between 2.84 and 4.07 g P kg−1 d.w., towards the end of the growing season.
- The greatest summer accumulation of P per unit area was observed in P. australis (34.7 kg P ha−1) among the native species. For this reason, particular attention should be paid to removing P. australis rushes, which should be done before the senescence and decay period.
- The potential of floodplain vegetation for summer phosphorus accumulation was estimated as 255 kg P year−1; however, a conversion of 24% or 48% of the area into fast-growing managed willow patches can increase phosphorus retention up to 332 or 399 kg P year−1, respectively. The “24%” scenario has been recommended in order to preserve the biodiversity of the river floodplain.

Edyta Kiedrzyńska, Iwona Wagner, Maciej Zalewski, **Quantification of phosphorus retention efficiency by floodplain vegetation and a management strategy for a eutrophic reservoir restoration**, Ecological Engineering, Volume 33, Issue 1, 1 May 2008, Pages 15-25, ISSN 0925-8574, http://dx.doi.org/10.1016/j.ecoleng.2007.10.010.

3.13. Landscape retention and terracing, retaining walls

For this study two different situations on a 100-m-long hillslope were studied: one in an undisturbed position, with natural vegetation and one in a disturbed two-year-old terraced vineyard. Samples of the soil surface from 0 to 20 cm were collected at several points along the slope for analysis of texture,

organic matter and aggregate stability. At these locations, saturated hydraulic conductivity was measured using a disc permeameter.

- The results show that in these soils with a high percentage of coarse elements (> 60%), work carried out during land transformation produced changes in the particle size distribution of the fine fraction. In addition, levelling reduced the organic matter content of the cultivated soils.
- These changes affected hydraulic conductivity, water retention capacity (which decreased by 45%) and aggregate stability, as well as the relationships between all these variables.
- A strong correlation was observed in both cases between water retention capacity at both potentials and the available water capacity, but while on the undisturbed plots these variables were correlated with hydraulic conductivity, this relationship was not observed in the new mechanised terraced vineyards.
- In addition, the strong correlation observed between aggregate stability and organic matter in the undisturbed plots is not clear on the new terraced plots. Instead, water stable aggregates and hydraulic conductivity seemed to show some correlation, but were not well correlated with the organic matter content.
- These facts confirm the changes taking place within the different land use scenarios analysed in relation to their physical and hydrologic soil properties.

María Concepción Ramos, Roser Cots-Folch, José A. Martínez-Casasnovas, **Effects of land terracing on soil properties in the Priorat region in Northeastern Spain: A multivariate analysis, Geoderma**, Volume 142, Issues 3–4, 15 December 2007, Pages 251-261, ISSN 0016-7061, http://dx.doi.org/10.1016/j.geoderma.2007.08.005.

Levelling is used in rice fields to correct land irregularities for management practice improvement. Effects of levelling have been evaluated using univariate tools from classical statistics and geostatistics, which disregard possible effects on interrelations among soil properties. This study aimed to: (i) evaluate the effect of levelling on soil physico-chemical properties using classical statistics and geostatistical tools, (ii) group soil properties in homogeneous sets using multivariate cluster analysis, (iii) reduce the dimensionality of sets by principal component analysis, and (iv) characterize and map spatial distributions of principal components to compare them with individual maps to elaborate maps of homogeneous management zones.

- The study shows the potential of multivariate analysis to evaluate land levelling.
- Geostatistical tools can be used to evaluate impacts caused by levelling.
- Levelling negatively affected lowland soil surface quality.
- Levelling affected spatial relationships among soil properties.
- Multivariate analysis can be used for the recuperation of degraded soils by levelling.
- Levelling caused an increase of the spatial range for the majority of the soil physico-chemical properties as well as an improvement of the goodness of fit to the models. The structure of the spatial variability of the majority of the evaluated soil physical properties was best modeled by the Gaussian semivariogram model while for the majority of the chemical properties the spherical model.
- Levelling caused changes in the variance and covariance structures of all physical and chemical properties of the soil surface layer which were detected by cluster multivariate analysis.
- The use of principal component and geostatistical analyses showed that the spatial map of the first principal component for the group of soil physical and of chemical properties can

potentially be used as a tool to define homogeneous areas of management aiming at the recuperation of degraded soils caused by levelling operations.

- Soil bulk density and organic matter represented the set of the evaluated soil physical and chemical properties that were most affected by land levelling, so that their maps are considered useful and accessible tools for farmers in future operations of land recuperation.

Sources: Dioni Glei Bonini Bitencourt, Willian Silva Barros, Luís Carlos Timm, Dongli She, Letiane Helwig Penning, José Maria Barbat Parfitt, Klaus Reichardt, **Multivariate and geostatistical analyses to evaluate lowland soil levelling effects on physico-chemical properties**, Soil and Tillage Research, Volume 156, March 2016, Pages 63-73, ISSN 0167-1987, http://dx.doi.org/10.1016/j.still.2015.10.004.

Soil studies of ancient agricultural fields contribute to research on long-term human–environmental relationships and land use sustainability. This kind of research is especially applicable in desert landscapes of the American Southwest because: (1) soil formation is slow enough that cultivation effects persist for centuries to millennia; (2) many ancient fields in valley margins have remained uncultivated since they were abandoned, so long-term soil properties reflect ancient agricultural use; and (3) agricultural features (e.g., terraces, rock alignments and rock piles, and irrigation canals) provide clues for identifying and sampling ancient cultivated and uncultivated soils.

- Knowledge of long-term soil change under traditional Southwest agricultural systems is relevant to present-day critical resource issues on regional and global scales, such as climate change and variability, and related problems of water supply and use, and desertification.
- Soil is a vital natural resource that past and present societies have relied on for their sustenance.
- Agriculture's impact on soils is complex in process and outcome, ranging from degradation in varying degrees and duration, to enhanced productivity and ecosystem function, as well as cases where outcomes seem minimal or uncertain. Soil is vulnerable to degradation that compromises its function and quality, and lowers crop productivity. Soil degradation continues to be a serious threat in the U.S. and throughout the world (Diamond, 2005, Hillel, 2008, Johnson and Lewis, 1995, Montgomery, 2007, Redman, 1999 and Sandor et al., 2005). The long-term record of soil use and change by humans provides perspectives important to advancing sustainable agriculture and land resource conservation.
- With some notable exceptions (e.g., terra preta soils in the Amazon Basin, plaggen soils in Europe, some ancient terraced soils in Peru and soils of Asian rice production systems), soil degradation is the most common outcome of agriculture on a world-wide basis (especially that caused by accelerated erosion, nutrient loss, and salinization), and similar outcomes are represented in the Southwest. Unlike many other parts of the world, it is interesting to note that numerous examples of soil enhancement are represented in agroecosystems of the Southwest. The American Southwest, with its long agricultural history and wide range of systems, environments, and effects, holds valuable evidence and lessons on soil and landscape change.

Jeffrey A. Homburg, Jonathan A. Sandor, Anthropogenic effects on soil quality of ancient agricultural systems of the American Southwest, CATENA, Volume 85, Issue 2, May 2011, Pages 144-154, ISSN 0341-8162, http://dx.doi.org/10.1016/j.catena.2010.08.005.

We reviewed literature describing the potential for freshwater anthropogenic waterbodies to act as refuges from disturbance. We identified research related to the refuge potential of a wide range of waterbodies, using waterbody names as keywords along with ‘artificial’ and ‘freshwater’. Potential

freshwater anthropogenic refuges were more often standing than running waters. Agricultural ponds, rural and urban drainage ditches and transport canals were the most diverse for all aquatic taxa, whereas irrigation infrastructure was least diverse. Comparatively little is known about the refuge role of fire dams, urban artificial ponds, golf course lakes, disused industrial ponds and retaining walls. Many knowledge gaps about the function of anthropogenic refuges within landscapes exist and require further research.

- One of the most important limitations to the provision of refuges for freshwater biodiversity by anthropogenic waterbodies is the lack of recognition of their actual or potential biodiversity value.
- Anthropogenic waterbodies need to be recognised for their potential to support biodiversity conservation and climate change adaptation for freshwater species, while being managed to prevent the spread of invasive species.
- We reviewed biodiversity of anthropogenic freshwaters and their refuge potential.
- Agricultural ponds, drainage ditches and transport canals had highest biodiversity.
- Moderate levels of management intervention were associated with higher biodiversity.
- Lack of recognition of actual or potential biodiversity value limits use as refuges.
- Management needs to recognize/enhance refuge function and control invasive species.

E.T. Chester, B.J. Robson, **Anthropogenic refuges for freshwater biodiversity: Their ecological characteristics and management**, Biological Conservation, Volume 166, October 2013, Pages 64-75, ISSN 0006-3207, http://dx.doi.org/10.1016/j.biocon.2013.06.016.

3.14. Water retention and biodiversity

Biodiversity was positively correlated with soil retention, water yield and carbon sequestration and negatively correlated with N/P retention and pollination.

- Pairwise overlap was found to be the highest between N and P retention, biodiversity and carbon sequestration, and biodiversity and water yield. Other couples indicated moderate or small overlap.
- Principal component analysis indicated that biodiversity and six ecosystem services could be divided into two groups, which could be managed and conserved separately. It can be concluded that biodiversity priorities co-occur with water yield, soil retention and carbon sequestration, and do not co-occur with N/P retention and pollination.
- Conservation of a biodiversity hotspot was associated with maintaining 45.02% of a carbon sequestration hotspot, 42.05% of a water yield hotspot, and 23.29% of a soil retention hotspot, indicating that conserving biodiversity will also result in the protection of these services.
- The bundling of biodiversity and ecosystem services is thus both possible and practical. Our findings provide valuable information on congruence and divergence among conservation hotspots and the protection of ecosystem services.
- They also indicate that a systematic and comprehensive approach that can have wide-ranging policy implications in terms of optimizing conservation strategies for multiple ecosystem services.
- Although there are many other potential tradeoffs – such as management efficiency, service beneficiaries and landholders – our systematic and comprehensive approach provides valuable information on the congruence and divergence among biodiversity hotspot and ecosystem services hotspots.

Yang Bai, Changwei Zhuang, Zhiyun Ouyang, Hua Zheng, Bo Jiang, **Spatial characteristics between biodiversity and ecosystem services in a human-dominated watershed**, Ecological Complexity, Volume 8, Issue 2, June 2011, Pages 177-183, ISSN 1476-945X, http://dx.doi.org/10.1016/j.ecocom.2011.01.007.

Riparian zones along streams and other small wetlands perform important ecosystem services in agricultural landscapes. They improve water quality by retaining nutrients and sediment from through-flowing water, sequester carbon and attenuate flood peaks at high discharge. At the same time, they have been shown to enhance biodiversity at the landscape as well as regional scale.

- Oligotrophic and mesotrophic wetlands such as bogs and fens are negatively affected by nutrient loadings > 4 g N m−2 y−1 and 0.5 g P m−2 y−1, which lead to loss of diversity and characteristic species.
- Wetlands in riparian zones are naturally more nutrient-rich and can tolerate much higher nutrient loadings without consequences for ecosystem health and diversity, their loading limits are 50 g N m−2 y−1 and 4 g P m−2 y−1.
- Studies from several parts of the world have further shown that wetland creation and restoration has definitely enhanced regional flora as well as fauna diversity in intensively used agricultural landscapes.
- As long as the nutrient loading of these wetlands does not surpass critical limits, plant and animal diversity is not threatened by the effects of the nutrient inputs. As in most agricultural landscapes the most mobile and highly leaching nutrient is nitrate, many riparian wetlands are subject to high nitrogen loads.
- Measures to keep the phosphorus loading low, will increase the chance that the wetland will be able to maintain its biodiversity.
- Hence, the potential for 'dual-purpose' wetlands is certainly there and may lead to a better water quality as well as strengthened regional biodiversity in agricultural landscapes.

Sources: Mariet M. Hefting, Ronald N. van den Heuvel, Jos T.A. Verhoeven, **Wetlands in agricultural landscapes for nitrogen attenuation and biodiversity enhancement: Opportunities and limitations, Ecological Engineering**, Volume 56, July 2013, Pages 5-13, ISSN 0925-8574, http://dx.doi.org/10.1016/j.ecoleng.2012.05.001.

Constructed wetlands, have been used to decrease nitrogen transport from agricultural catchments to the coast of Sweden, while simultaneously contributing to increased species richness in the landscape. The purpose of this paper is to compile and evaluate data that have been produced in Sweden during some 20 years of using constructed wetlands as an environmental tool.

- Individual wetlands can have a high nitrogen removal, making wetland construction a cost effective tool. A question that remains to be answered is if it would be possible to achieve these high removal values in large wetland creation programs. Our analyses indicate that improved planning of wetland programs, including improved design of wetlands and selection of wetland locations, is needed if desired environmental effects are to be achieved on a large scale.
- The effects of constructed wetlands in Sweden on the species numbers and population sizes of wetland birds and amphibians were large enough to positively affect the occurrence of species in the national red list, i.e. on a national population level.
- Species numbers were high also for nutrient removal wetlands showing that it is possible to get multiple ecosystem services out of the constructed wetlands.

John A. Strand, Stefan E.B. Weisner, **Effects of wetland construction on nitrogen transport and species richness in the agricultural landscape—Experiences from Sweden**, Ecological Engineering, Volume 56, July 2013, Pages 14-25, ISSN 0925-8574, http://dx.doi.org/10.1016/j.ecoleng.2012.12.087.

The assessment of the value of ecosystem services is a valuable tool for biodiversity conservation that can facilitate better environmental policy decision-making and land management, and can help land managers develop interventions to compensate for biodiversity loss at the patch level. Previous studies have suggested that it is appropriate to assess the value of biodiversity for conservation planning by considering both the condition of the landscape and the spatial configuration of adjacent land uses that can be reflected as a proximity effect. This research examines the influence of spatial proximity on biodiversity conservation from the ecosystem service perspective based on the assumption that the variation in the proximity effect caused by land cover change has positive or negative impacts on ecological services. Three factors related to the spatial characteristics of the landscape were considered in this approach: the relative artificiality of the land cover types, the distance decay effect of patches and the impact of one land cover type on others. The proximity effect change (PEC) parameter reflected the relationship between the spatial proximity effect and biodiversity conservation.

- This research provided a place-based approach to assess the influence of the proximity effect on biodiversity conservation.
- A new metric was developed to reflect the relationship between the spatial proximity effect and biodiversity conservation.
- A quantitative and spatial comparative analysis examined the temporal and spatial variation in biodiversity conservation.
- The method can identify critical areas for biodiversity protection and inform strategies to maximize biodiversity benefits.
- The method also provides information to identify the most critical areas for biodiversity protection and to guide the reasonable allocation of land by accounting for biological conservation and regional development in landscape planning.
- This study provides a means to consider the spatial characteristics related to the influence of proximity in evaluating changes in ecosystem services for biodiversity conservation.
- It also provides information to minimize the negative effects of changing land cover, particularly urban expansion and cropland conversion.

Yanfang Liu, Lei Zhang, Xiaojian Wei, Peng Xie, Integrating the spatial proximity effect into the assessment of changes in ecosystem services for biodiversity conservation, Ecological Indicators, Volume 70, November 2016, Pages 382-392, ISSN 1470-160X, http://dx.doi.org/10.1016/j.ecolind.2016.06.019.

We reviewed literature describing the potential for freshwater anthropogenic waterbodies to act as refuges from disturbance. We identified research related to the refuge potential of a wide range of waterbodies, using waterbody names as keywords along with ‘artificial’ and ‘freshwater’

- We reviewed biodiversity of anthropogenic freshwaters and their refuge potential.
- Agricultural ponds, drainage ditches and transport canals had highest biodiversity.
- Moderate levels of management intervention were associated with higher biodiversity.
- Lack of recognition of actual or potential biodiversity value limits use as refuges.
- Management needs to recognize/enhance refuge function and control invasive species.
- Freshwater anthropogenic habitats could be managed to improve their capacity to support biodiversity through consideration of their qualities as refuges; and without necessarily

including them in direct restoration or preventing continuing human use of these areas (Table 2).

- The concept of anthropogenic refuges intersects well with the growing literature on reconciliation ecology and the ways in which artificial or heavily modified ecosystems may sustain biodiversity in urban, industrial and agricultural landscapes. While extensive habitat restoration is not usually possible in such landscapes, attributes that allow constructed features of the landscape to function as habitat can be enhanced. However, further research is needed to establish the interdependence between anthropogenic refuges and other habitat.
- While it is clear that many freshwater species can survive in landscapes heavily dominated by human activities, we do not yet know whether anthropogenic habitat can function alone as a refuge network, or whether it functions as an adjunct to preserved natural habitat or restored areas. This currently represents the largest knowledge gap (Table 2).
- In all cases, the largest limitation to anthropogenic waterbodies providing refuges for freshwater biodiversity is the lack of recognition of their actual, or potential, biodiversity value. Presently, many of these habitats are ignored or denigrated as part of water management policy and this means that they are likely to be destroyed as part of water management or development processes (Gómez and Araujo, 2008, Brainwood and Burgin, 2009, Canals et al., 2011 and Casas et al., 2011), without first considering their function as refuges in the landscape.

E.T. Chester, B.J. Robson, Anthropogenic refuges for freshwater biodiversity: Their ecological characteristics and management, Biological Conservation, Volume 166, October 2013, Pages 64-75, ISSN 0006-3207, http://dx.doi.org/10.1016/j.biocon.2013.06.016.

3.15. Floodplain restoration and ecosystem services

Floodplain ecosystems are biodiversity hotspots and supply multiple ecosystem services. At the same time they are often prone to human pressures that increasingly impact their intactness. Multifunctional floodplain management can be defined as a management approach aimed at a balanced supply of multiple ecosystem services that serve the needs of the local residents, but also those of off-site populations that are directly or indirectly impacted by floodplain management and policies.

- Efficient use of management resources and ecosystem services, consensual solutions need to be realized and biodiversity needs to be mainstreamed into management activities to maximize ecosystem service provision and potential human benefits.
- The impacts of the implemented measures on biodiversity and the provision of ecosystem services are largely undocumented and under-researched.
- The scarcity of multifunctional approaches is also reflected by the lack of large-scale vision in the management and use of rivers and floodplains beyond county, federal or national boundaries, integrating all disciplines and stakeholders over extended areas, such as the floodplains of a whole catchment or at least significant functional parts of it.
- Multifunctionality is more successful where a broad range of stakeholders with diverse expertise and interests are involved in all stages of planning and implementation.

Source: Schindler, S. et al. **Multifunctional floodplain management and biodiversity effects**: a **knowledge synthesis for six European countries.** Biodiversity and Conservation 25, 1349–1382 (2016).

- Systematic comparisons on the effects of different stream restoration techniques are rare.
- Herein we compare the effects of four substratum restoration measures in six streams.
- We apply an integrative approach to assess the effects on multiple biological scales.
- The biological effects were surprisingly small and restricted in time.
- Restoration measures should be scientifically tested before being applied in practice.

Sources: Melanie Mueller, Joachim Pander, Juergen Geist, **The ecological value of stream restoration measures: An evaluation on ecosystem and target species scales**, Ecological Engineering, Volume 62, January 2014, Pages 129-139, ISSN 0925-8574, http://dx.doi.org/10.1016/j.ecoleng.2013.10.030.

Exploitation of freshwater resources is essential for sustenance of human existence and alteration of rivers, lakes and wetlands has facilitated economic development for centuries. Consequently, freshwater biodiversity is critically threatened, with stream ecosystems being the most heavily affected. To improve the status of freshwater habitats, e.g. in the context of the European Water Framework Directive and the US Clean Water Act, it is essential to implement the most effective restoration measures and identify the most suitable indicators for restoration success.

- This is essential for the development of national restoration concepts and the protection of important ecosystem services (drinking water, food supply, economy).
- The restoration of stream ecosystem health and ecosystem services can be most successful when target-oriented, systematic, and integrative approaches are used to determine initial conditions and to measure restoration effects. A stepwise evaluation of the primary factors of disturbance or degradation may be most suitable when considering all major drivers of successful restoration.
- The PCoR presented herein integrates the standardised approach for scientific monitoring into a step-by-step guideline for river restoration, politics, and management. Systematic approaches in stream restoration planning should follow the principle of comprehensiveness, adequacy, representativeness, and efficiency (CARE principle, Linke et al., 2011) to match the PCoR criteria. Target species (important as indicator, flagship, umbrella and keystone species) based approaches, as presented herein and in Geist (2010), in combination with assessments of ecosystem processes can fulfil the criteria of the CARE principle.
- Merging the interactions between abiotic and biotic factors at different levels of organisation qualitatively and quantitatively, as proposed in the IFEBC concept (Geist, 2011), with practical conservation and the PCoR concept is likely to increase the efficiency of aquatic restoration and targeted ecosystem services in the future. Ultimately any effort to make restoration more effective will be beneficial to preserve aquatic biodiversity.

Sources: Joachim Pander, Juergen Geist, **Ecological indicators for stream restoration success, Ecological Indicators**, Volume 30, July 2013, Pages 106-118, ISSN 1470-160X, http://dx.doi.org/10.1016/j.ecolind.2013.01.039.

Restoring lateral hydraulic connectivity between wetlands, fringe habitats and riparian land with the adjacent river channel is extremely important to maintain natural functioning of floodplain wetlands. However, there is no simple solution to restoring and rehabilitating rivers and their floodplains, particularly in terms of long-term sustainability. Floodplains are often the most fertile and productive part of the landscape, in terms of both agricultural production and natural ecosystems. Restoration projects must be able to balance conflicting needs and interests.

- We explore wetland/floodplain dynamics and how they are impacted by human activities in Europe.
- It is underline how hydro-morphological dynamics are driving and delivering floodplains restoration for a range of benefit.
- We focus on the value of wetland restoration in the context of balancing conservation, agricultural and social needs.
- It is presented a picture of European policy and its role in context of wetland/floodplain conservation/restoration.
- Participatory processes and tools are presented as key point for an effective sustainable management.

Sources: Bruna Gumiero, Jenny Mant, Thomas Hein, Josu Elso, Bruno Boz, **Linking the restoration of rivers and riparian zones/wetlands in Europe: Sharing knowledge through case studies**, Ecological Engineering, Volume 56, July 2013, Pages 36-50, ISSN 0925-8574, http://dx.doi.org/10.1016/j.ecoleng.2012.12.103.

This paper explores changes in rural land use in floodplains by measuring the range of ecosystem services provided under different management scenarios. Generic land use scenarios consider management options that focus on single objectives, such as maximising agricultural production, maximising biodiversity and maximising flood storage capacity. Indicators are developed to value the ecosystem services provided by floodplains under each scenario, identifying potential synergy and conflict.

- There is conflict, for example, between agricultural production and environmental outcomes such as water quality, greenhouse gas balance, habitat and species.
- There is for example,potential synergy between short duration flood storage (to deliver benefits to urban areas downstream) and agricultural production. Contrary to popular belief, there can be potential conflict between flood storage and biodiversity. Some wetland habitats and species are sensitive to flooding and yet require high ditch and water table levels that use up potential flood storage capacity.
- 'Making space for water' that aims amongst other things to reconnect rivers with floodplains, may not always provide flood risk managers with the degree of hydraulic control required to hold back flood waters and prevent downstream urban flooding. The methods here provide a basis for quantifying these relationships, recognising the impor- tance of local conditions.
- The financial performance of different land uses under each scenario is sensitive to farm output and input prices and agri- environment payments. This has implications for the design and implementation (i) of hybrid or composite land and water manage- ment scenarios that will be beneficial and robust under a range of future possible conditions, and (ii) of policy and support regimes that will make such scenarios appealing to the main stakeholders, especially land managers, conservationists, flood managers and local communities.
- Developing methodologies to estimate quantities and values for ecosystem services is challenging but necessary in order to take the ecosystem approach forward. This case study shows that estimation of indicators enables synergies and conflicts between ecosystem services to be revealed.

Sources: H. Posthumus, J.R. Rouquette, J. Morris, D.J.G. Gowing, T.M. Hess, **A framework for the assessment of ecosystem goods and services; a case study on lowland floodplains in England**, Ecological Economics, Volume 69, Issue 7, 15 May 2010, Pages 1510-1523, ISSN 0921-8009, http://dx.doi.org/10.1016/j.ecolecon.2010.02.011.

Previously regarded as the passive drains of watersheds, over the past 50 years, rivers have progressively been recognized as being actively connected with off-channel environments. These connectionsprolong physical storage and enhance reactive processing to alter water chemistry and downstream trans-port of materials and energy. Here we propose river corridor science as a concept that integrates down-stream transport with lateral and vertical exchange across interfaces. Thus, the river corridor, rather than thewetted river channel itself, is an increasingly common unit of study. Main channel exchange with recirculat-ing marginal waters, hyporheic exchange, bank storage, and overbank flow onto floodplains are all includedunder a broad continuum of interactions known as ''hydrologic exchange flows.''

- Hydrologists, geomorphol-ogists, geochemists, and aquatic and terrestrial ecologists are cooperating in studies that reveal thedynamic interactions among hydrologic exchange flows and consequences for water quality improvement,modulation of river metabolism, habitat provision for vegetation, fish, and wildlife, and other valued ecosys-tem services.
- The need for better integration of science and management is keenly felt, from testing effectiveness of stream restoration and riparian buffers all the way to reevaluating the definition of the waters ofthe United States to clarify the regulatory authority under the Clean Water Act.
- A major challenge for scien-tists is linking the small-scale physical drivers with their larger-scale fluvial and geomorphic context and eco-logical consequences. Although the fine scales of field and laboratory studies are best suited to identifyingthe fundamental physical and biological processes, that understanding must be successfully linked tocumulative effects at watershed to regional and continental scales.

Source: Harvey, J., and M. Gooseff (2015), **Rivercorridor science: Hydrologic exchangeand ecological consequences frombedforms to basins**, Water Resour. Res.,51, 6893–6922, doi:10.1002/2015WR017617.

This study uses geospatial methods to fill this gap by assessing the National Commodity Crops Productivity Index (NCCPI) soil values and agricultural production and profit values for corn and soybeans in 32 individual levee districts along a 235-km segment of the Lower Illinois River. In general, soil productivity index values were lower for Illinois River levee districts compared to the county averages in which the districts are located. Over the five-year study period from 2010 to 2014, the total agricultural profits in the levee districts ranged from $18–61 million. Several levee districts have relatively low per hectare agricultural values when compared to the value of wetland benefits, indicating these protected floodplain areas may be more suitable for reconnection.

- Assessment of agricultural value of floodplain levee districts.
- Improved methodology to assess potential restoration costs and benefits of agricultural land.
- No direct relationship between levee protection level and agricultural value.
- Previous estimates of per hectare wetland benefits outweigh the agricultural benefits currently provided along the Lower Illinois River.
- Multiple districts with low agricultural profit values can be analyzed further in floodplain reconnection studies.

Guida, R. J.; Remo, J. W. F.; Secchi, S. **Applying geospatial tools to assess the agricultural value of Lower Illinois River floodplain levee districts.** Applied Geography 2016, 74, 123–135.

- Ecosystem services are useful for assessing trade-offs in water quality management.
- We trialled the approach in the Tully–Murray catchment, Great Barrier Reef and found.
- Trade-offs between food production, water quality regulation, tourism and fisheries.
- Symmetry between private stakeholders: farmers, tour operators, tourists and fishermen.
- Scale mis-matches between ecosystem service flows and water quality governance.

Sources: James R.A. Butler, Grace Y. Wong, Daniel J. Metcalfe, Miroslav Honzák, Petina L. Pert, Nalini Rao, Martijn E. van Grieken, Tina Lawson, Caroline Bruce, Frederieke J. Kroon, Jon E. Brodie, **An analysis of trade-offs between multiple ecosystem services and stakeholders linked to land use and water quality management in the Great Barrier Reef**, Australia, Agriculture, Ecosystems & Environment, Volume 180, 1 November 2013, Pages 176-191, ISSN 0167-8809, http://dx.doi.org/10.1016/j.agee.2011.08.017.

- Multi criteria analysis was applied to evaluate and quantify ecosystem trade-offs.
- Enhanced water input improved the ecological conditions of floodplain habitats.
- Enhanced water input reduced maximum potential for drinking water production.
- Trade-off between the two ecosystem services were quantified at 0.50 score.
- Majority of stakeholders preferred the increased hydraulic connectivity options.

Source: Samai Sanon, Thomas Hein, Wim Douven, Peter Winkler, **Quantifying ecosystem service trade-offs: The case of an urban floodplain in Vienna**, Austria, Journal of Environmental Management, Volume 111, 30 November 2012, Pages 159-172, ISSN 0301-4797,

4. Practical Conclusions

In Chapter 3 a comprehensive review is given about wide range of studies in connection with natural small water retention measures (NSWRM) using a literature search methodology which was described in Chapter 2. The NSWRM topic covers several combinations of key issues that the literature discusses, such as water retention in landscape, groundwater, floodplain, aquifer or soil with combinaton, among others: afforestation, soil structure, organic matter, tillage riparian buffers, biofiltration, wetlands, polders, ponds, terracing, ecosystem services.

The literature review reveals that dominant part of the studies concentrate on one or only a limited number of combinations where NSWRMs are applied. It was also recognised from the literature review that though there were large number of studies which described the processes where NSWRMs were involved, but the information gained from these studies were limited in terms of how these measures / experiments were setup, what initial and boundary conditions were applied, what parameters were studied, etc.

However, there are guidence documents available, which introduce, in principle, several number of technical as well as non-technical measures with general description of their individual quantitative and in some cases qualitative impacts on water resources, mostly in local scale. But in practice, especially in river basin management planning and implementation there is a growing need for deeper understanding of impacts of NSWRMs when these measures are used not only in local scale, but in a larger area (small, medium or even in large size river basins) with combinations of several of technical and/or non-technical NSWRMs. In such practical situations some important questions should be answered with confidence, such as:

- In which river basin – or river basin sub-region – should the NSWRMs be applied to improve water resources availability for different water resources management purposes?
- What method(s) can be applied to determine where are the needs for NSWRMs?
- What is the cummulative effectiveness of NSWRMs when these measures are applied not only individually, but in different combinations?
- How cummulative effectiveness of NSWRMs can be assessed / evaluated when these are applied in combinations?
- Which parameters should be taken into account for
    - determining the area where NSWRMs are needed,
    - evaluation of effectivess of NSWRMs applied in combinations and in larger areas?

- How to evaluate the cummulative benefits of application of NSWRMs in combinations?

It turned out from the accomplished literature review which discussed in Chapter 3 that there is a well defined knowledge gap when one wants to answer for the above listed questions. Especially there is hardly any applicable integrated method which can handle the issues of NSWRMs applied in combination or cumulatively.

Consequently, one of the practical conclusions of the knowledge gap analysis study is that it would be most beneficial to elaborate – through a project using knowledge from international partners – a method /tool (or serious of tools) that could handle the questions listed above. Such an international project should address: a) elaboration of valorisation method for identifying locations in a river basin where NSWRMs are needed, b) development of innovative method / tool (decision support system) for river basin authorities to evaluate the cummulative effectiveness of the system of NSWRMs at river basin scale, c) preparation of a Guideline document, which provides decision makers with policy options and cost analysis method for implementation of NSWRMs.

An other practical conclusion is that the literature review highlighted that certain information can be revealed from the papers about: i) conditions influencing NSWRM effectiveness (such as appropriate terrain conditions, processes influencing NSWRM), ii) benefits of NSWRM, iii) effects of NSWRM (on floods, droughts, biodiversity, sediment and nutrient transport). Some of the litarature papers provide information as well about the parameters applicable for these issues, which can be applied in a well structured, innovative decision support system.

There are different approaches how a problem oriented decision support system can be setup. For those problem areas where combination of already well defined natural phenomenon and its established mathematical description and knowledge of experts that is not available in mathematical formulas the usually the solution is to formulate rules for different combinations of the possible solutions.

The introduction of artificial intelligence on personal computers in the form of knowledge representation makes it possible to develop rule based expert systems, which could facilitate the selection of a particular solutions.

For example in our case - to identify the best combination(s) of NSWRMs in a given river basin a rule based decidion expert system could applicable. Rule based decidion expert systems are "computer programs" that are built in a way to have knowledge and capacity which will allow them to operate on an expert's level". These programs are designed to simulate the problem-solving behavior of human beings who are experts in specialized areas. Expert systems differ from conventional computer programs since knowledge, which is usually represented in the form of rules in the expert system, is treated separately from the problem-solving mechanism, called the inference engine. Because of their nonalgorithmic, modular structure, rule based expert systems are also much easier to be developed, maintained, or modified. The rules in an expert system are text representations of knowledge, and are structured in the form of conditional "if-then" logical decisions. The rules allow a program to arrive at its conclusion (decision) when the inference procedure executes them. The inference procedure can be of the backward- or forward-chaining type. In backward chaining, the inference engine automatically checks all rules to see if there is one that could provide the required information. By contrast, forward chaining can only be used as a method of testing rules that are not goal driven. Rules in this case are simply tested in the order in which they were implemented.

As a conclusion it can be stated that a rule based decidion expert system could be established for i) identification of the locations in a river basin where NSWRMs would be needed; ii) determination of conditions influencing NSWRM effectiveness (such as appropriate terrain conditions, processes influencing NSWRM); iii) getting the cummulative effectiveness of NSWRMs applied not only individually, but in different combinations; iv) which parameters should be taken into account for

determining the area where NSWRMs are needed. The inference procedure which would solve a rule base for such a complex problem field is typically a backward chaining one.