



European  
Commission

# EVALUATING THE IMPACT OF NATURE-BASED SOLUTIONS

## Appendix of Methods

Independent  
Expert  
Report



Green space  
management



Knowledge building  
for sustainable urban  
transformation



Place  
regeneration



Health and  
well-being



Participatory planning  
and governance



Climate resilience



Biodiversity  
enhancement



Water  
management



New economic  
opportunities and  
green jobs



Natural and  
climate hazards



Air quality



Social justice and  
social cohesion

Research and  
Innovation

## Evaluating the Impact of Nature-based Solutions: Appendix of Methods

European Commission  
Directorate-General for Research and Innovation  
Directorate C — Healthy Planet  
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**EVALUATING THE IMPACT OF**  
**NATURE-BASED**  
**SOLUTIONS**

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**Appendix of Methods**

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# Table of Contents

<b>1 RECOMMENDED INDICATORS OF CLIMATE RESILIENCE</b> .....	21
1.1 Carbon removed or stored in vegetation and soil .....	21
1.2 Avoided greenhouse gas emissions from reduced building energy consumption .....	24
1.3 TX <sub>x</sub> , Monthly mean value of daily maximum temperature .....	26
1.4 TN <sub>n</sub> , Monthly mean value of daily minimum temperature.....	27
1.5 Heatwave Incidence .....	29
<b>2 ADDITIONAL INDICATORS OF CLIMATE RESILIENCE</b> .....	31
2.1. Carbon storage and sequestration in vegetation .....	31
2.1.1 Carbon storage and sequestration in vegetation per unit area per unit time .....	31
2.1.2 Carbon storage and sequestration in vegetation – annual determination .....	34
2.1.3 Total Leaf Area .....	36
2.1.4 Carbon Storage Score.....	38
2.1.5 Measured soil carbon content .....	40
2.1.6 Modelled carbon content of the upper soil layer .....	43
2.1.7 Soil carbon decomposition rate.....	44
2.2 Energy use savings due to green infrastructure implementation .....	46
2.3 Estimated carbon emissions reduction from building energy saving - cooling .....	49
2.4 Energy and CO <sub>2</sub> emissions savings from reduced volume of water entering sewers .....	52
2.5 Soil Temperature.....	55
2.6 Total surface area of wetlands.....	57
2.7 Surface area of restored and/or created wetlands .....	59
2.8 Aboveground tree biomass .....	61
2.9 Human Comfort.....	62
2.9.1 Universal Thermal Climate Index (UTCI) .....	62
2.9.2 Thermal Comfort Score (TCS) .....	65
2.9.3 Physiological equivalent temperature (PET) .....	68
2.9.4 Predicted Mean Vote-Predicted Percentage Dissatisfied (PMV-PPD).....	70
2.10 Urban Heat Island Effect .....	72
2.10.1. Urban Heat Island (UHI) incidence .....	72
2.10.2. Number of combined tropical nights and hot days .....	74
2.10.3 Thermal Storage Score .....	76
2.10.4 Thermal Load Score .....	78
2.11 Estimated reduction in peak summer temperature .....	81
2.12 Maximum surface cooling .....	83
2.13 Mean or peak daytime temperature.....	85
2.13.1 Mean or peak daytime temperature - Direct temperature measurement .....	85
2.13.2 Mean or peak daytime temperature - Temperature modelling.....	87
2.14 Daily Temperature Range (DTR) .....	89
2.15 Cooling of ambient air.....	90
2.15.1 Air cooling .....	90
2.15.2 Air temperature reduction .....	93
2.16 Tree shade for local heat reduction.....	107
2.17 Rate of evapotranspiration.....	119
2.18 Land surface temperature.....	122
2.19 Surface reflectance - Albedo .....	125
2.20 Estimated carbon emissions from vehicle traffic.....	130
<b>3 RECOMMENDED INDICATORS OF WATER MANAGEMENT</b> .....	132
3.13 Surface runoff in relation to precipitation quantity .....	132

3.13.1	Direct measurement.....	132
3.13.2	Curve Number method.....	134
3.13.3	Rational method.....	137
3.13.4	Intensity-Duration-Frequency (IDF) curve method.....	140
3.13.5	Process-based hydraulic modelling.....	143
3.14	Water Quality – general urban.....	147
3.15	Total Suspended Solids (TSS) content.....	154
3.16	Nitrogen and phosphorus concentration or load.....	157
3.17	Metal concentration or load.....	160
3.18	Total faecal coliform bacteria.....	163
<b>4</b>	<b>ADDITIONAL INDICATORS OF WATER MANAGEMENT.....</b>	<b>167</b>
4.13	Measured infiltration rate and capacity.....	167
4.14	Calculated infiltration rate and capacity.....	170
4.15	Evapotranspiration rate.....	173
4.16	Peak flow variation.....	176
4.17	Flood peak reduction and delay.....	179
4.18	Height of flood peak and time to flood peak measurement.....	185
4.19	Flood excess volume (FEV).....	187
4.20	Rainfall interception rate of NBS.....	191
4.21	Runoff rate for different rainfall events.....	193
4.22	Run-Off Score.....	194
4.23	Rainfall storage capacity of NBS.....	196
4.24	Quantitative status of groundwater.....	202
4.25	Depth to groundwater.....	204
4.26	Groundwater chemical status.....	206
4.27	Trend in piezometric levels (TPL).....	210
4.28	Groundwater exploitation index (GEI).....	211
4.29	Aquifer surface ratio with excessive nitrate.....	214
4.30	Aquifer surface ratio with excessive arsenic.....	216
4.31	Water availability for irrigation purposes.....	218
4.32	Water Exploitation Index.....	220
4.33	Water dependency for food production.....	222
4.34	Calculated drinking water provision.....	224
4.35	Net surface water availability.....	225
4.36	Volume of water removed from water treatment system.....	226
4.37	Volume of water slowed down entering sewer system.....	228
4.38	Total surface area of wetlands within a defined area.....	230
4.39	Total surface area of restored and/or created wetlands.....	232
4.40	Soil water flux.....	234
4.41	Soil water retention capacity.....	236
4.42	Stemflow rate.....	238
4.43	Percolation rate under different rainfall events.....	239
4.44	Dissolved oxygen (DO) content of NBS effluents.....	241
4.45	Eutrophication.....	243
4.46	pH of NBS effluents.....	244
4.47	Electrical conductivity of NBS effluents.....	247
4.48	Water Framework Directive: Physico-chemical quality of surface waters.....	249
4.49	Total pollutant discharge to local waterbodies.....	253
4.50	Water Quality: basic physical parameters.....	255
4.51	Total polycyclic hydrocarbon (PAH) content of NBS effluents.....	257
4.52	Total organic carbon (TOC) content of NBS effluents.....	260

4.53	General ecological status of surface waters .....	262
4.54	Ecological potential for heavily modified or artificial water bodies .....	265
4.55	Biological quality of surface waters .....	268
4.56	Total number and species richness of aquatic macroinvertebrates .....	271
4.57	Morphological Quality Index (MQI) .....	274
4.58	Hydromorphological quality of surface waters .....	278
4.59	Fluvial Functionality Index .....	280
<b>5</b>	<b>RECOMMENDED INDICATORS OF NATURAL AND CLIMATE HAZARDS .....</b>	<b>283</b>
5.13	Disaster Resilience .....	283
5.14	Disaster-risk informed development .....	285
5.15	Mean annual direct and indirect losses due to natural and climate hazards .....	286
5.16	Risk to critical urban infrastructure .....	289
5.17	Mean number of people adversely affected by natural disasters each year .....	295
5.18	Multi-hazard early warning .....	298
<b>6</b>	<b>ADDITIONAL INDICATORS OF NATURAL AND CLIMATE HAZARDS .....</b>	<b>300</b>
6.13	Potential areas exposed to risks .....	300
6.13.1	Urban/residential areas .....	300
6.13.2	Productive areas .....	301
6.14	Natural areas, sites of community importance and special protection areas .....	302
6.15	Potential population exposed to risks .....	303
6.15.1	Inhabitants .....	303
6.15.2	Area and population exposed to flooding .....	304
6.15.3	Other people (workers, tourists, homeless) .....	308
6.15.4	Elderly, children, disabled .....	309
6.16	Potential Population Vulnerable to Risks .....	310
6.16.1	Population .....	310
6.17	Potential buildings exposed to risks .....	311
6.17.1	Housing .....	311
6.17.2	Agricultural and industrial buildings .....	312
6.17.3	Strategic Buildings (Hospitals, schools, etc.) .....	313
6.18	Potential infrastructures exposed to risks .....	314
6.18.1	Roads .....	314
6.18.2	Railways .....	315
6.18.3	Lifelines .....	316
6.19	Potential infrastructures vulnerable to risks .....	318
6.19.1	Buildings .....	318
6.19.2	Transportation infrastructures and lifelines .....	319
6.20	Insurance against catastrophic events .....	320
6.21	Flood hazard .....	321
6.22	Flooded area .....	323
6.23	Height of flood peak and time to flood peak .....	324
6.24	Peak flow rate .....	326
6.25	Peak flood volume .....	327
6.26	Flood excess volume .....	329
6.27	Moisture index .....	333
6.28	Flammability index .....	334
6.29	Soil Type .....	335
6.30	Soil strength .....	336
6.31	Soil temperature .....	338
6.32	Level of Groundwater Table .....	339

6.33 Shallow landslide risk – slope stability factor of safety .....	340
6.34 Landslide safety factor .....	341
6.35 Landslide risk – History of instability on site.....	343
6.36 Occurred landslide area.....	344
6.37 Landslide risk – Digital elevation/terrain modelling.....	345
6.38 Soil mass movement .....	347
6.39 Velocity of occurred landslide .....	348
6.40 Erosion risk.....	349
6.41 Total Predicted Soil Loss (RUSLE).....	351
6.42 Days with temperature >90 <sup>th</sup> percentile (TX90p) .....	352
6.43 Warm spell duration index (WSDI) .....	354
6.44 Heatwave incidence.....	355
6.45 Human comfort: Universal thermal climate index (UTCI) .....	357
6.46 Human comfort: Physiological equivalent temperature (PET).....	360
6.47 Human comfort Predicted Mean Vote-Predicted Percentage Dissatisfied (PMV-PPD) .....	363
6.48 Urban Heat Island (UHI) incidence .....	365
6.49 Effective drought index .....	366
6.50 Standardized Precipitation Index.....	367
6.51 Groundwater level.....	369
6.52 Trend in piezometric levels (TPL) .....	371
6.53 Groundwater exploitation index .....	373
6.54 Calculated drinking water provision .....	375
6.55 Water Exploitation Index .....	377
6.56 Net surface water availability .....	379
6.57 Water availability for irrigation purposes .....	380
6.58 Avalanche Risk: Snow cover map.....	383
<b>7 RECOMMENDED INDICATORS OF GREEN SPACE MANAGEMENT .....</b>	<b>385</b>
7.1 Green space accessibility .....	385
7.2 Total green space within a defined area: Share of green urban areas .....	391
7.3 Soil organic matter .....	394
7.3.1 Soil Organic Matter Index.....	395
<b>8 ADDITIONAL INDICATORS OF GREEN SPACE MANAGEMENT .....</b>	<b>398</b>
8.1 Ecosystem service provision .....	398
8.2 Annual trend in vegetation cover in urban green infrastructure .....	406
8.3 Edge density.....	411
8.3.1 Public green space distribution (applied and EO/RS).....	413
8.5 Distribution of blue space.....	418
8.6 Effective green infrastructure in the urban-rural interface .....	423
8.7 Hot spot in peri-urban green infrastructure.....	425
8.8 Biotope Area Factor .....	428
8.9 Total vegetation cover .....	431
8.9.1 Woody vegetation cover.....	432
8.9.2 Non-woody vegetation cover.....	433
8.9.3 Total Leaf Area .....	434
8.10 Diversity of green space.....	436
8.11 Stages of forest stand development -Number of class diameter .....	437
8.12 Tree regeneration .....	439
8.13 Canopy gaps .....	440
8.14 Tree biomass stock change .....	441
8.15 Soil carbon content .....	442

8.15.1 Measured soil carbon content .....	442
8.15.2 Modelled carbon content of the upper soil layer .....	445
8.15.3 Soil carbon to nitrogen ratio .....	446
8.15.4 Soil carbon decomposition rate .....	450
8.16 Soil matric potential .....	451
8.17 Soil temperature.....	452
8.18 Soil water holding capacity (field capacity) .....	454
8.19 Plant-available water .....	455
8.19.1 Plant available soil water .....	455
8.19.2 Soil water available for plant uptake (SAW metric).....	457
8.20 Vegetation Wilting Point .....	459
8.21 Soil water flux and degree of soil saturation.....	460
8.22 Stemflow funnelling ratio.....	462
8.23 Soil Erodibility .....	464
8.24 Total Predicted Soil Loss (RUSLE).....	465
8.25 Soil Ecotoxicological Factor .....	466
8.26 Soil structure .....	468
8.27 Soil chemical fertility .....	470
8.28 Flammability Index.....	472
8.29 Community garden area .....	473
8.30 Food production in urban allotments and NBS .....	476
8.31 Recreational opportunities provided by green infrastructure .....	478
8.31.1 ESTIMAP nature-based recreation model .....	480
8.31.2 Number of visitors in new recreational areas .....	486
8.31.3 Number of and reasons for visits to an NBS area .....	488
8.31.4 Frequency of use of green and blue spaces .....	491
8.31.5 Activities allowed in recreational areas.....	493
8.32 Visual access to green space .....	494
8.32.1 Viewshed .....	496
8.33 Satisfaction with green and blue spaces .....	497
8.34 Betweenness centrality .....	499
8.35 Proportion of road network dedicated to pedestrians and/or bicyclists.....	502
8.35.1 New pedestrian, cycling and horse paths.....	503
8.35.2 Sustainable transportation modes allowed.....	505
8.36 New links between urban centres and NBS .....	506
8.37 Walkability.....	507
8.38 Land composition.....	509
8.39 Land use change and green space configuration .....	512
8.40 Soil sealing .....	516
8.41 Ambient pollen concentration .....	521
<b>9 RECOMMENDED INDICATORS OF BIODIVERSITY ENHANCEMENT .....</b>	<b>524</b>
9.1 Structural and functional connectivity of urban green and blue spaces.....	524
9.1.1 Structural connectivity of green space .....	539
9.1.2 Functional connectivity of urban green and blue spaces .....	540
9.2 Number of native species .....	541
9.3 Number of non-native species introduced .....	543
9.3.1 Number of invasive alien species .....	545
9.4 Species diversity within defined area per Shannon Diversity Index.....	546
9.5 Number of species within defined area per Shannon Evenness Index.....	548
<b>10 ADDITIONAL INDICATORS OF BIODIVERSITY ENHANCEMENT .....</b>	<b>550</b>



10.1 Proportion of natural areas within a defined urban zone .....	550
10.2 Area of habitats restored .....	551
10.3 Shannon Diversity Index of habitats .....	553
10.3.1 Abundance of ecotones/Shannon diversity .....	555
10.4 Length of ecotones .....	556
10.5 Publicly accessible green space connectivity .....	558
10.6 Ecological integrity .....	561
10.7 Proportion of protected areas .....	564
10.7.1 Sites of community importance and special protection areas .....	566
10.7.2 Article17 habitat richness .....	567
10.8 Number of veteran trees per unit area .....	569
10.9 Quantity of dead wood per unit area .....	571
10.10 Forest habitat fragmentation – Effective Mesh Density .....	573
10.11 Extent of habitat for native pollinator species .....	575
10.12 Polluted soils .....	578
10.13 Soil food web stability .....	580
10.14 Modelled C and N cycling in soil .....	582
10.15 Equivalent used soil .....	583
10.16 Number/proportion of conservation priority species .....	585
10.17 Article17 species richness .....	588
10.18 Number of native bird species within a defied urban area .....	590
10.19 Species diversity – general .....	591
10.19.1 City Biodiversity Index .....	602
10.20 Bird species richness .....	604
10.21 Animal species potentially at risk .....	606
10.22 Typical vegetation species cover .....	608
10.23 Pollinator species presence .....	609
10.24 Biodiversity Conservation .....	611
10.25 Metagenomic mapping .....	623
10.25.1 Abundance of functional groups .....	624
10.25.2 Diversity of functional groups (plants) .....	626
10.25.3 Diversity of functional groups (animals) .....	627
<b>11 RECOMMENDED INDICATORS OF AIR QUALITY .....</b>	<b>630</b>
11.1 Number of days during which air quality parameters exceed threshold values .....	630
11.2 Proportion of population exposed to ambient air pollution .....	635
11.3 European Air Quality Index .....	641
<b>12 ADDITIONAL INDICATORS OF AIR QUALITY .....</b>	<b>647</b>
12.1 Removal of atmospheric pollutants by vegetation .....	647
12.2 Total particulate matter removed by NBS vegetation .....	649
12.3 Modelled O <sub>3</sub> , SO <sub>2</sub> , NO <sub>2</sub> and CO capture/removal by vegetation .....	651
12.3.1 Total Leaf Area .....	654
12.4 NO <sub>x</sub> and PM in gaseous releases .....	655
12.5 Ambient pollen concentration .....	660
12.6 Trends in NO <sub>x</sub> and SO <sub>x</sub> emissions .....	662
12.7 Concentration of particulate matter (PM <sub>10</sub> and PM <sub>2.5</sub> ), NO <sub>2</sub> , and O <sub>3</sub> in ambient air .....	666
12.8 Concentration of particulate matter at respiration height along roads .....	669
12.9 Mean level of exposure to ambient air pollution .....	672
12.10 Morbidity, Mortality and Years of Life Lost due to poor air quality .....	676
12.11 Avoided costs for air pollution control measures .....	679
<b>13 RECOMMENDED INDICATORS OF PLACE REGENERATION .....</b>	<b>683</b>

13.1 Derelict land reclaimed for NBS .....	683
13.2 Quantity of blue-green space as ratio to built form .....	685
13.3 Perceived quality of urban green, blue and blue-green spaces .....	686
13.4 Place attachment (Sense of Place): Place identity .....	692
13.5 Recreational value of public green space .....	699
13.6 Incorporation of environmental design in buildings .....	704
13.7 Preservation of cultural heritage .....	706
<b>14 ADDITIONAL INDICATORS OF PLACE REGENERATION .....</b>	<b>709</b>
14.1 Share of Green Urban Areas .....	709
14.2 Land composition .....	711
14.3 Land take index .....	717
14.4 Area devoted to roads .....	718
14.5 Traditional knowledge and uses reclamation .....	719
14.6 Traditional events organised in NBS areas .....	721
14.7 Social active associations .....	723
14.8 Retail and commercial activity in proximity to green space .....	724
14.9 Number of new businesses created and gross value added to local economy .....	726
14.10 Social return on investment .....	728
14.11 Population mobility .....	736
14.12 Population growth .....	738
14.13 Proportion of elderly residents .....	740
14.14 Areal sprawl .....	742
14.15 Access to public amenities .....	744
14.16 NBS distance from urban centres and public transport .....	750
14.17 Natural and cultural sites made available .....	751
14.18 Historical and cultural meaning .....	753
14.19 Cultural value of blue-green spaces .....	755
14.20 Opportunities for tourism .....	759
14.21 Building structure – Urban form .....	760
14.22 Material used coherence .....	765
14.23 Techniques used coherence .....	767
14.24 Design for sense of place .....	768
14.25 Viewshed .....	770
14.26 Scenic sites and landmarks created .....	772
14.27 Scenic paths created .....	774
<b>15 RECOMMENDED INDICATORS OF KNOWLEDGE AND SOCIAL CAPACITY BUILDING FOR SUSTAINABLE URBAN TRANSFORMATION .....</b>	<b>776</b>
15.1 Citizen involvement in environmental education activities .....	776
15.2 Social learning regarding ecosystems and their functions/services .....	782
15.3 Pro-environmental identity .....	784
15.4 Pro-environmental behaviour .....	790
<b>16 ADDITIONAL INDICATORS OF KNOWLEDGE AND SOCIAL CAPACITY BUILDING FOR SUSTAINABLE URBAN TRANSFORMATION .....</b>	<b>800</b>
16.1 Children involved in environmental educational activities .....	800
16.2 Engagement with NBS sites/projects .....	802
16.3 Mindfulness .....	805
16.4 Proportion of schoolchildren involved in gardening .....	806
16.5 Citizens’ awareness regarding urban nature and ecosystem services .....	808
16.6 Green intelligence awareness .....	811
16.7 Positive environmental attitudes motivated by contact with NBS .....	816

16.8 Urban farming educational and/or participatory activities .....	825
17 RECOMMENDED INDICATORS OF PARTICIPATORY PLANNING AND GOVERNANCE.....	827
17.1 Openness of participatory processes.....	827
17.1.1 Openness of participatory processes: proportion of citizens involved .....	833
17.2 Sense of empowerment: perceived control and influence over decision-making .....	834
17.3 Public-private partnerships activated .....	842
17.4 Policy learning for mainstreaming NBS.....	843
17.5 Trust in decision-making procedure and decision-makers .....	845
<b>18 ADDITIONAL INDICATORS OF PARTICIPATORY PLANNING AND GOVERNANCE .....</b>	<b>850</b>
18.1 Community involvement in planning .....	850
18.1.1 Citizen involvement in co-creation/co-design of NBS .....	852
18.1.2 Stakeholder involvement in co-creation/co-design of NBS .....	853
18.2 Community involvement in implementation .....	854
18.3 Involvement of citizens from traditionally under-represented groups .....	856
18.4 Active engagement of citizens in decision-making .....	858
18.5 Consciousness of citizenship .....	860
18.6 Number of governance innovations adopted.....	862
18.7 Adoption of new forms of NBS (co-)financing .....	866
18.8 Development of a climate resilience strategy (extent).....	868
18.9 Alignment of climate resilience strategy with UNISDR-defined elements .....	870
18.10 Adaptation of local plans and regulations to include NBS.....	872
18.11 Perceived ease of governance of NBS.....	874
18.12 Diversity of stakeholders involved .....	876
<b>19 RECOMMENDED INDICATORS OF SOCIAL JUSTICE AND SOCIAL COHESION .....</b>	<b>911</b>
19.1 Bridging and bonding – quality of interactions within and between social groups.....	911
19.1.1 Bridging.....	911
19.1.2 Bonding .....	915
19.2 Inclusion of different social groups in NBS projects.....	919
19.3 Trust within the community .....	922
19.4 Solidarity among neighbours.....	927
19.5 Tolerance and respect.....	931
19.6 Availability and equitable distribution of blue-green space .....	936
<b>20 ADDITIONAL INDICATORS OF SOCIAL JUSTICE AND SOCIAL COHESION .....</b>	<b>939</b>
20.1 Linking social capital.....	939
20.2 Perceived social interaction .....	944
20.3 Quantity and quality of social interaction .....	946
20.4 Perceived social support.....	947
20.4.1 Perception of socially supportive network .....	947
20.4.2 Perceived social support.....	949
20.5 Perceived social cohesion .....	950
20.6 Perceived ownership of space and sense of belonging to the community.....	951
20.7 Proportion of community who volunteer .....	954
20.8 Proportion of target group reached by an NBS project.....	956
20.9 Perceived personal safety .....	958
20.10 Perceived safety of neighbourhood .....	961
20.11 Number of violent incidents, nuisances and crimes per 100 000 population .....	968
20.12 Realised safety .....	970
20.13 Area easily accessible for people with disabilities.....	974
20.14 Change in properties incomes.....	975

<b>21 RECOMMENDED INDICATORS OF HEALTH AND WELLBEING</b> .....	977
21.1 Level of outdoor physical activity .....	977
21.2 Level of chronic stress (Perceived stress) .....	983
21.3 General wellbeing and happiness .....	984
21.4 Self-reported mental health and wellbeing .....	989
21.5 Cardiovascular diseases (prevalence, incidence, morbidity and mortality) .....	990
21.6 Quality of Life .....	996
<b>22 ADDITIONAL INDICATORS OF HEALTH AND WELL-BEING</b> .....	999
22.1 Self-reported physical activity .....	999
22.2 Observed physical activity level within NBS .....	1000
22.3 Encouraging a healthy lifestyle .....	1002
22.4 Incidence of obesity .....	1004
22.5 Heat-related discomfort: Universal Thermal Climate Index (UTCI) .....	1009
22.6 Hospital admissions due to high temperature during extreme heat events .....	1012
22.7 Heat-related mortality .....	1013
22.8 Exposure to noise pollution .....	1018
22.9 Perceived chronic loneliness .....	1023
22.10 Somatisation .....	1026
22.11 Mindfulness .....	1028
22.12 Visual access to green space .....	1029
22.13 Perceived restorativeness of public green space/ NBS .....	1031
22.14 Perceived social support .....	1037
22.15 Connectedness to nature .....	1038
22.16 Prevalence of attention deficit/ hyperactivity disorder (ADHD) .....	1039
22.17 Exploratory behaviour in children .....	1043
22.18 Self-reported anxiety .....	1046
22.19 Prevalence, incidence, morbidity and mortality of respiratory diseases .....	1048
22.20 Morbidity, Mortality and Years of Life Lost due to poor air quality .....	1054
22.21 Prevalence and incidence of autoimmune diseases .....	1057
22.22 Prevalence, incidence and morbidity of chronic stress .....	1062
<b>23 RECOMMENDED INDICATORS OF NEW ECONOMIC OPPORTUNITIES AND GREEN JOBS</b> .....	1068
23.1 Valuation of NBS .....	1068
23.1.1 Value of NBS calculated using GI-Val .....	1068
23.1.2 Economic Value of Urban Nature Index .....	1072
23.2 Mean land and/or property value in proximity to green space .....	1074
23.2.1 Change in mean house prices/ rental markets .....	1077
23.2.2 Average land productivity and profitability .....	1079
23.2.3 Property betterment and visual amenity enhancement .....	1080
23.3 Number of new jobs created .....	1082
23.4 Retail and commercial activity in proximity to green space .....	1085
23.5 Number of new businesses created and gross value added to local economy .....	1087
23.6 Recreational monetary value .....	1089
23.7 Overall economic, social and health wellbeing .....	1092
<b>24 ADDITIONAL INDICATORS OF NEW ECONOMIC OPPORTUNITIES AND GREEN JOBS</b> .....	1097
24.1 New businesses established in proximity to NBS .....	1097
24.2 Value of rates paid by businesses in proximity to NBS .....	1099
24.3 New customers to businesses in proximity to NBS .....	1101
24.4 Local economy GDP .....	1104
24.5 Initial costs of NBS implementation .....	1107
24.6 Maintenance costs of NBS .....	1109

24.7 Replacement costs of NBS .....	1110
24.8 Avoided costs due to NBS implementation .....	1112
24.9 Payback period for NBS.....	1113
24.10 Reduced/avoided damage costs .....	1115
24.11 Social Return on Investment (SROI) .....	1116
24.12 Income produced via application of green policies .....	1125
24.13 Subsidies applied for private NBS measures .....	1126
24.14 Private finance attracted to the NBS site.....	1129
24.15 Increase in tourism.....	1132
24.16 New activities in the tourism sector .....	1133
24.17 Gross profit from nature-based tourism .....	1135
24.18 Number of new jobs in green sector.....	1137
24.19 Jobs created in NBS construction and maintenance.....	1140
24.20 New employment in the tourism sector .....	1142
24.21 Turnover in the green sector .....	1143
24.22 Employment in agriculture .....	1145
24.23 Rural Productivity Index .....	1146
24.24 Economic value of productive activities vulnerable to risks .....	1148
24.25 Innovation impact .....	1149
24.26 Income/Disposable income per capita .....	1154
24.26.1 Monthly disposable income .....	1157
24.27 Upskilling and related earnings increase .....	1159
24.28 Population mobility .....	1162
24.29 Avoided cost of run-off treatment.....	1163
24.30 Correction Cost of Groundwater Quality.....	1166
24.31 Dissuasive cost of water abstraction .....	1168
24.32 Average water productivity .....	1169
24.33 New areas made available for traditional productive uses.....	1170
24.34 Value of food produced.....	1172
24.35 Renewable energy produced.....	1173

# WATER MANAGEMENT

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## 3 RECOMMENDED INDICATORS OF WATER MANAGEMENT

### 3.13 Surface runoff in relation to precipitation quantity

#### 3.13.1 Direct measurement

**Project Name:** UNaLab (Grant Agreement no. 730052), CLEVER Cities (Grant Agreement no. 776604) and GROW GREEN (Grant Agreement no. 730283)

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Runoff coefficient – direct measurement	Water Management
<b>Description and justification</b>	The extent of impermeable surfaces in urban areas is continually increasing as cities develop and expand, due to the construction of buildings, roads, streets, parking lots, etc. A significant consequence is greater runoff in urban areas, which can also lead to flooding. Many factors are affecting the quantity of surface runoff, including soil

	<p>characteristics, land use and vegetative cover, hillslope, and storm properties such as rainfall duration, amount, and intensity (Sitterson et al. 2017). In general, surface runoff is generated in two ways (Yang, Li, Sun &amp; Ni, 2014): through saturation excess, where runoff is generated when the soil becomes saturated (for example after a lengthy period of rainfall); or, through infiltration excess, where runoff is generated when the rainfall intensity exceeds the infiltration rate of water into the soil (for example during a heavy precipitation event when rain falls more rapidly than it can infiltrate the soil).</p>
<b>Definition</b>	Runoff coefficient in relation to precipitation quantities (m <sup>3</sup> /s, L/s or depth-equivalent mm)
<b>Strengths and weaknesses</b>	<ul style="list-style-type: none"> <li>+ Traditional, well-studied method for open channel flow measurement</li> <li>+ Scalable for different purposes</li> <li>- Requires judgement in case of equipment malfunction</li> </ul>
<b>Measurement procedure and tool</b>	<p>Direct measurement of runoff (and its characteristics) using standard approaches, including weirs, pressure transducers/loggers, tipping-bucket gauges, etc. (e.g., Stovin et al., 2012).</p> <p>Large scale: Weirs, flumes, orifices. Weirs obstruct the flow making the head behind the weir being a function of flow velocity and flow rate through the weir. Flumes are another traditional method for open channel flow measurement in a channel with converging and diverging sections. The operation principle of the flumes is that the water level is higher in the converging section than in the diverging section, and that there is direct relationship between water depth and flow rate (Adkins, 2006).</p> <p>Small scale: tipping-bucket gauges, pressure transducers for discharge monitoring. Tipping-bucket gauges record runoff volumes as numbers of bucket tips per 24-h period. The depth of the daily runoff is then calculated by dividing the volume of daily runoff by the area of the test plot (Armson, Stringer, and Ennos, 2013). Pressure transducers allow for automatic continuous monitoring and data collection at certain intervals (e.g., 1-min) (Stovin, Vesuviano, and Kasmin, 2012).</p>
<b>Scale of measurement</b>	Plot or building scale to district scale
<b>Data source</b>	
<b>Required data</b>	Runoff measurements
<b>Data input type</b>	Quantitative

<b>Data collection frequency</b>	Annually; at minimum, before and after NBS implementation
<b>Level of expertise required</b>	Moderate – ability to evaluate the accuracy of measurements is required (in case of equipment malfunction)
<b>Synergies with other indicators</b>	Direct relation to <i>Height of flood peak</i> and <i>Time to flood peak</i> indicators
<b>Connection with SDGs</b>	SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities
<b>Opportunities for participatory data collection</b>	No opportunities identified
<b>Additional information</b>	
<b>References</b>	Adkins, G.B. (2006). Flow Measurement Devices. Utah Division of Water Rights, Utah. Armson, D., Stringer, P. & Ennos, A.R. (2013). The effect of street trees and amenity grass on -urban surface water runoff in Manchester, UK. <i>Urban Forestry &amp; Urban Greening</i> , 12, 282-286. Stovin, V., Vesuviano, G. & Kasmin, H. (2012). The hydrological performance of a green roof test bed under UK climatic conditions. <i>Journal of Hydrology</i> , 414-415, 148-161

### 3.13.2 Curve Number method

**Project Name:** UNaLab (Grant Agreement no. 730052), CLEVER Cities (Grant Agreement no. 776604) and GROW GREEN (Grant Agreement no. 730283)

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Runoff coefficient – Curve Number		Water Management
<b>Description and justification</b>	The extent of impermeable surfaces in urban areas is continually increasing as cities develop and expand, due to the construction of buildings, roads, streets, parking lots, etc. A significant consequence is greater runoff in urban areas, which can also lead to flooding. Many factors are	



	<p>affecting the quantity of surface runoff, including soil characteristics, land use and vegetative cover, hillslope, and storm properties such as rainfall duration, amount, and intensity (Sitterson et al. 2017). In general, surface runoff is generated in two ways (Yang, Li, Sun &amp; Ni, 2014): through saturation excess, where runoff is generated when the soil becomes saturated (for example after a lengthy period of rainfall); or, through infiltration excess, where runoff is generated when the rainfall intensity exceeds the infiltration rate of water into the soil (for example during a heavy precipitation event when rain falls more rapidly than it can infiltrate the soil).</p>
<b>Definition</b>	Runoff in relation to precipitation quantity (mm)
<b>Strengths and weaknesses</b>	<p>+ The most widely used modelling method to estimate runoff from rainfall</p> <p>+ Particularly useful for comparing pre- and post-development peak rates, volumes, and hydrographs</p> <p>- Curve number varies due to differences in rainfall intensity and duration, total rainfall, soil moisture conditions, cover density, stage of growth, and temperature</p>
<b>Measurement procedure and tool</b>	<p>USDA Curve Number – Taking into account losses (interception, infiltration and storage) as well as antecedent moisture conditions – runoff is estimated for storm events. Published Curve Numbers (CN) can be used in the equation. CN values are function of soil, hydrological conditions and landcover (can be weighted). Widely used worldwide. Soil Conservation Service (1972). Used in context of NBS (Gill et al, 2007).</p> <p>Steps to produce the value for the storm runoff include:</p> <ol style="list-style-type: none"> <li>1. Determine the value of <i>CN</i> for the specific cover type, hydrologic condition, and hydrologic soil group, using Table 9-1 in the USDA National Engineering Handbook (2004).</li> <li>2. Determine the value for <i>S</i> based on the <i>CN</i> value, using Table 10-1 in the USDA National Engineering Handbook (2004) or equation for the <i>CN</i>.</li> <li>3. Determine the runoff (<i>Q</i>) either using the graphical solution or tables provided by the USDA National Engineering Handbook (2004). For the determination, values for rainfall and <i>CN</i> are needed. Other possibility to determine the runoff is to use the runoff equation where values for rainfall and <i>S</i> are needed.</li> </ol> <p>The curve number equation to estimate runoff from rainfall is:</p>

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \quad P > I_a$$

$$Q = 0 \quad P \leq I_a$$

Where  $Q$  is depth of runoff (in),  $P$  is depth of rainfall (in),  $I_a$  is initial abstraction (in), and  $S$  is maximum potential retention (in).

The initial abstraction ( $I_a$ ) consists mainly of interception, infiltration during early parts of a storm, and surface depression storage. The initial abstraction can be determined from rainfall-runoff events for small watersheds. However, estimation of the initial abstraction is not easy and  $I_a$  has been assumed to be a function of the maximum potential retention ( $S$ ). An empirical relationship between  $I_a$  and  $S$  has been expressed as (USDA, 2004):

$$I_a = 0.2S$$

With this relationship, the original runoff equation can be written in a more simplified form:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \quad P > I_a$$

The runoff based on curve number can be determined based on graphs or tables provided by USDA (2004). The parameter  $CN$  is a transformation of potential maximum retention,  $S$  (in mm):

$$CN = \frac{1000}{10 + \frac{S}{25.4}}$$

<b>Scale of measurement</b>	District scale to metropolitan area scale
<b>Data source</b>	
<b>Required data</b>	Hydrologic soil group (HSG), land use/cover, hydrologic surface condition and antecedent moisture condition
<b>Data input type</b>	Quantitative
<b>Data collection frequency</b>	Annually; at minimum, before and after NBS implementation
<b>Level of expertise required</b>	High – requires ability to execute the calculations, use the graphical solutions and evaluate the results

<b>Synergies with other indicators</b>	Direct relation to <i>Height of flood peak</i> and <i>Time to flood peak</i> indicators
<b>Connection with SDGs</b>	SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities
<b>Opportunities for participatory data collection</b>	No opportunities identified
<b>Additional information</b>	
<b>References</b>	United States Department of Agriculture (USDA). (2004). National Engineering Handbook Part 630 Hydrology. Washington, D.C.: United States Department of Agriculture, Natural Resources Conservation Service. Retrieved from <a href="https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/manage/hydrology/?cid=STELPRDB1043063">https://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/water/manage/hydrology/?cid=STELPRDB1043063</a>

### 3.13.3 Rational method

**Project Name:** UNaLab (Grant Agreement no. 730052), CLEVER Cities (Grant Agreement no. 776604) and GROW GREEN (Grant Agreement no. 730283)

**Author/s and affiliations:** Laura Wendling<sup>1</sup>, Ville Rinta-Hiiro<sup>1</sup>, Maria Dubovik<sup>1</sup>, Arto Laikari<sup>1</sup>, Johannes Jermakka<sup>1</sup>, Zarrin Fatima<sup>1</sup>, Malin zu-Castell Rüdénhausen<sup>1</sup>, Peter Roebeling<sup>2</sup>, Ricardo Martins<sup>2</sup>, Rita Mendonça<sup>2</sup>, Maddalen Mendizabal<sup>3</sup>

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Runoff coefficient – Rational method	Water Management
<b>Description and justification</b>	The extent of impermeable surfaces in urban areas is continually increasing as cities develop and expand, due to the construction of buildings, roads, streets, parking lots, etc. A significant consequence is greater runoff in urban areas, which can also lead to flooding. Many factors are affecting the quantity of surface runoff, including soil characteristics, land use and vegetative cover, hillslope, and storm properties such as rainfall duration, amount, and intensity (Sitterson et al. 2017). In general, surface runoff is generated in two ways (Yang, Li, Sun & Ni, 2014): through saturation excess, where runoff is generated when the soil becomes saturated (for example after a lengthy period of rainfall); or, through infiltration excess, where runoff is generated when the rainfall intensity exceeds the infiltration rate of water into the soil (for example during a

	heavy precipitation event when rain falls more rapidly than it can infiltrate the soil).										
<b>Definition</b>	Runoff in relation to precipitation quantity (m <sup>3</sup> /s or L/s)										
<b>Strengths and weaknesses</b>	<p>+ A widely used method, which gives an empirical relation between rainfall intensity and peak flow</p> <p>- Requires significant judgment and understanding from the designer</p> <p>- For the method, several assumptions that are seldom met under natural conditions must be made</p>										
<b>Measurement procedure and tool</b>	<p>Rational Method for estimating 'peak' flow rates for simple urban watersheds/sewers. Often used for design discharges. Requires rainfall intensity, the runoff-coefficient (can be derived from published value) and watershed area (Kuichling, 1889).</p> <p>A simplified outline of the necessary steps to determine peak runoff using the Rational Method is:</p> <ol style="list-style-type: none"> <li>Determine the runoff coefficient (<math>C</math>). Typical values are listed in textbooks and manuals (e.g., Viessman &amp; Lewis, 2003; VDOT, 2002). If needed, use a saturation factor (<math>C_f</math>) for storms with a recurrence intervals less than 10 years. These higher intensity storms require modification to estimation of runoff. Saturation factors are given by reference books and design manuals. Note that the saturation factor <math>C_f</math> multiplied by the runoff coefficient <math>C</math> should not exceed 1.0. Saturation factors (<math>C_f</math>) for rational formula (VDOT, 2002).</li> </ol> <table border="1" data-bbox="431 1100 934 1323"> <thead> <tr> <th><b>Recurrence Interval (Years)</b></th> <th><b><math>C_f</math></b></th> </tr> </thead> <tbody> <tr> <td><b>2, 5 and 10</b></td> <td>1.0</td> </tr> <tr> <td><b>25</b></td> <td>1.1</td> </tr> <tr> <td><b>50</b></td> <td>1.2</td> </tr> <tr> <td><b>100</b></td> <td>1.25</td> </tr> </tbody> </table> <ol style="list-style-type: none"> <li>Determine the time of concentration (<math>T_c</math>) to estimate the average rainfall intensity (<math>i</math>). The methods for determining the time of concentration are described by, e.g., VDOT (2002). One of them is that the time of concentration is the time required for water to flow from the hydraulically most remote point in the drainage area to the point of study.</li> <li>Determine the rainfall intensity (<math>i</math>). It is assumed that the duration is equal to the time of concentration. The rainfall intensity can be selected from the IDF curve.</li> <li>Solve the equation of the Rational Method to obtain the estimated peak runoff:</li> </ol>	<b>Recurrence Interval (Years)</b>	<b><math>C_f</math></b>	<b>2, 5 and 10</b>	1.0	<b>25</b>	1.1	<b>50</b>	1.2	<b>100</b>	1.25
<b>Recurrence Interval (Years)</b>	<b><math>C_f</math></b>										
<b>2, 5 and 10</b>	1.0										
<b>25</b>	1.1										
<b>50</b>	1.2										
<b>100</b>	1.25										

	$Q = C_f C_i A$ <p>Where <math>Q</math> is maximum rate of runoff (cfs), <math>C_f</math> is saturation factor, <math>C_i</math> is runoff coefficient representing a ratio of runoff to rainfall (dimensionless), <math>i</math> is average rainfall intensity for a duration equal to the time of concentration for a selected return period (in/hr), and <math>A</math> is drainage area contributing to the point of study (ac).</p>
<b>Scale of measurement</b>	Plot or building scale to district scale. Used mostly for relatively small drainage areas, such as parking lots. The use should be limited to drainage areas <20 acres (ca. 8 ha).
<b>Data source</b>	
<b>Required data</b>	Rainfall intensity, drainage area, saturation factor, runoff coefficient
<b>Data input type</b>	Quantitative
<b>Data collection frequency</b>	Annually; at minimum, before and after NBS implementation
<b>Level of expertise required</b>	High – requires significant judgement on adequacy of calculated values
<b>Synergies with other indicators</b>	Direct relation to <i>Height of flood peak</i> and <i>Time to flood peak</i> indicators
<b>Connection with SDGs</b>	SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities
<b>Opportunities for participatory data collection</b>	No opportunities identified
<b>Additional information</b>	
<b>References</b>	<p>Dhakai, N., Fang, X., Asquith, W.H. &amp; Cleveland, T. (2013). Return period adjustment for runoff coefficients based on analysis in undeveloped Texas watersheds. <i>Journal of Irrigation and Drainage Engineering</i>, June 2013</p> <p>Hayes, D.C., &amp; Young, R.L. 2005. Comparison of Peak Discharge and Runoff Characteristic Estimates from the Rational Method to Field Observations for Small Basins in Central Virginia. Scientific Investigations Report 2005-5254. Reston, VA: United States Geological Survey.</p> <p>Viessman, W. &amp; Lewis, G.L. (2003). <i>Introduction to Hydrology</i>. 5th edition. Upper Saddle River, NJ: Prentice Hall</p> <p>Virginia Department of Transportation (VDOT). (2019). <i>Drainage Manual</i>. Location and Design Division. Issued April 2002. Rev. March 2019. Richmond, VA: Virginia Department of Transportation. Retrieved from</p>

### 3.13.4 Intensity-Duration-Frequency (IDF) curve method

**Project Name:** UNaLab (Grant Agreement no. 730052), CLEVER Cities (Grant Agreement no. 776604) and GROW GREEN (Grant Agreement no. 730283)

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Runoff coefficient – IDF curves	Water Management
<b>Description and justification</b>	The extent of impermeable surfaces in urban areas is continually increasing as cities develop and expand, due to the construction of buildings, roads, streets, parking lots, etc. A significant consequence is greater runoff in urban areas, which can also lead to flooding. Many factors are affecting the quantity of surface runoff, including soil characteristics, land use and vegetative cover, hillslope, and storm properties such as rainfall duration, amount, and intensity (Sitterson et al. 2017). In general, surface runoff is generated in two ways (Yang, Li, Sun & Ni, 2014): through saturation excess, where runoff is generated when the soil becomes saturated (for example after a lengthy period of rainfall); or, through infiltration excess, where runoff is generated when the rainfall intensity exceeds the infiltration rate of water into the soil (for example during a heavy precipitation event when rain falls more rapidly than it can infiltrate the soil).
<b>Definition</b>	Runoff in relation to precipitation quantity (L/s or m <sup>3</sup> /s)
<b>Strengths and weaknesses</b>	+ IDF analysis provides a convenient tool for summarizing regional rainfall information and thus it is useful in municipal stormwater management practices - Requires significant judgment and understanding from the designer - Requires fairly extensive historic rainfall data
<b>Measurement procedure and tool</b>	Statistical estimation of 'peak' runoff rates for return periods of 5,10,100 years based on rainfall and

	<p>catchment characteristics (area, channel slope, length, soil permeability). E.g. IH124 or FEH methods (UK).</p> <p>A summary of the steps necessary to create IDF curves is given by Mirrhosseini et al. (2013):</p> <ol style="list-style-type: none"> <li>1. Obtain annual maximum series of precipitation depth for a given duration (15 min, 30 min, 45 min, 1 h, 2 h, 3 h, 6 h, 12 h, 24 h, and 48 h)</li> <li>2. Use a suitable probability distribution (e.g., generalized extreme value per Mirrhosseini et al., 2013) to find precipitation depths for different return periods (2, 5, 10, 25, 50, and 100 y). One of the most common probability distributions used in the IDF analysis is Gumbel's extreme value distribution (Wang &amp; Huang 2004).</li> <li>3. Repeat the first two steps for different durations</li> <li>4. Plot rainfall intensity versus duration for different frequencies</li> </ol> <p>In addition, other possible probability distributions can be used.</p> <p>Another possibility to create IDF curves is to use the equation (MTO 1997):</p> $i = A / (t_d + B)^c$ <p>Where <math>i</math> is average rainfall intensity (mm/h), <math>t_d</math> is rainfall duration (min) and <math>A</math>, <math>B</math>, and <math>c</math> are coefficients. The coefficients can be solved by least squares method described in the Ontario Drainage Management Manual produced by the Ministry of Transportation of Ontario (MTO, 1997). When the coefficients are solved, the above equation can be used to produce plots of rainfall intensity vs. duration for different return periods (Wang &amp; Huang 2004).</p>
<b>Scale of measurement</b>	Different sizes of catchments, district scale to region scale
<b>Data source</b>	
<b>Required data</b>	Recorded rainfall data (historic) and catchment characteristics (area, channel length, soil permeability)
<b>Data input type</b>	Quantitative
<b>Data collection frequency</b>	Annually; at minimum, before and after NBS implementation
<b>Level of expertise required</b>	High – requires ability and significant judgement to execute statistical analyses
<b>Synergies with other indicators</b>	Direct relation to <i>Height of flood peak</i> and <i>Time to flood peak</i> indicators

<b>Connection with SDGs</b>	SDG 6 Clean water and sanitation, SDG 11 Sustainable cities and communities
<b>Opportunities for participatory data collection</b>	No opportunities identified
<b>Additional information</b>	
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### 3.13.5 Process-based hydraulic modelling

**Project Name:** UNaLab (Grant Agreement no. 730052), CLEVER Cities (Grant Agreement no. 776604) and GROW GREEN (Grant Agreement no. 730283)

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Runoff coefficient – Process-based hydraulic modelling	Water Management
<b>Description and justification</b>	The extent of impermeable surfaces in urban areas is continually increasing as cities develop and expand, due to the construction of buildings, roads, streets, parking lots, etc. A significant consequence is greater runoff in urban areas, which can also lead to flooding. Many factors are affecting the quantity of surface runoff, including soil characteristics, land use and vegetative cover, hillslope, and storm properties such as rainfall duration, amount, and intensity (Sitterson et al. 2017). In general, surface runoff is generated in two ways (Yang, Li, Sun & Ni, 2014): through saturation excess, where runoff is generated when the soil becomes saturated (for example after a lengthy period of rainfall); or, through infiltration excess, where runoff is generated when the rainfall intensity exceeds the infiltration rate of water into the soil (for example during a heavy precipitation event when rain falls more rapidly than it can infiltrate the soil).
<b>Definition</b>	Runoff in relation to precipitation quantity (mm)
<b>Strengths and weaknesses</b>	<ul style="list-style-type: none"> <li>+ Possibility to extrapolate the measurements spatially and temporally</li> <li>+ Allows for future predictions and forecasts given the available measurements</li> <li>- Modelling includes numerous simplifications and approximations (adequacy of process parametrizations, data limitations and uncertainty, and computational constraints on model analysis)</li> <li>- Multiple challenges arise when choosing the approach to modelling</li> </ul>
<b>Measurement procedure and tool</b>	One-dimensional and two-dimensional drainage system modelling exist. There are many examples of models applied in an urban context. Existing approaches used to evaluate GI/NBS are the Stormwater Management Model (SWMM [USA]), CityCat (Newcastle), MIKE (DHI) and InfoWorks for

Sustainable Drainage Systems (SUDS [UK]). Impact of climate change on runoff can be evaluated using the design storms. The models typically require multiple parameters for accurate results.

1. The modelling process starts with a perceptual model, which is the summary of perceptions of how the catchment responds to rainfall under different conditions. In the conceptual model, mathematical descriptions are formed where hypotheses and assumptions are taken into account.
2. If the equations decided in the conceptual model cannot be solved analytically given some boundary conditions for the real system, an additional stage of approximation is necessary using the techniques of numerical analysis to define a procedural model. This is given in a form of code that will run on the computer.
3. In the next phase, the parameters used in the model needs to be calibrated. The most commonly used method in the model calibration is matching the model predictions and observations from the direct measurements if they are available.
4. After the calibration of parameters, simulations with the model could be made. Results of the simulations should then be reviewed and the model validated. The validation can be done by comparing the results to direct measurements, e.g., observed discharges, if they are available (Beven 2012).

When choosing a conceptual model, the following procedure can be used (Beven, 2012):

- Prepare a list of the models under consideration.
- Prepare a list of the variables predicted by each model. Decide if the model under consideration will give the needed output.
- Prepare a list of the assumptions made by the model. Reject models where the assumptions are estimated to be too inaccurate.
- Make a list of the inputs required by the model, for specification of the flow domain, the boundary and initial conditions and the parameter values.
- Determine whether you have any models left on your list. If not, the criteria should be reviewed again and then review the previous steps.

Comparison of the basic structure for rainfall- runoff models (adapted from Sitterson et al., 2017):

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Empirical	Conceptual	Physical
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	<b>Method</b>	Non-linear relationship between inputs and outputs, black box concept	Simplified equations that represent water storage in catchment	Physical laws and equations based on real hydrologic responses
	<b>Strengths</b>	Small number of parameters needed, can be more accurate, fast run time	Easy to calibrate, simple model structure	Incorporates spatial and temporal variability, very fine scale
	<b>Weaknesses</b>	No connection between physical catchment, input data distortion	Does not consider spatial variability within catchment	Large number of parameters and calibration needed, site specific
	<b>Best Use</b>	In ungauged watersheds, runoff is the only output needed	When computational time or data are limited	Have great data availability on a small scale
	<b>Examples</b>	Curve Number, Artificial Neural Networks <sup>(a)</sup>	HSPF <sup>(b)</sup> , TOPMEDEL <sup>(a)</sup> , HBV <sup>(a)</sup> , Stanford <sup>(a)</sup>	MIKE-SHE <sup>(a)</sup> , KINEROS <sup>(c)</sup> , VIC <sup>(a)</sup> , PRMS <sup>(d)</sup>
	<sup>a</sup> Devia, Ganasri, & Dwarakish, 2015 <sup>b</sup> Johnson, Coon, Mehta, Steenhuis, Brooks, & Boll, 2003 <sup>c</sup> Woolhiser, Smith, & Goodrich, 1990 <sup>d</sup> Singh, 1995			
<b>Scale of measurement</b>	All scales depending on the type of model used			
<b>Data source</b>				
<b>Required data</b>	Rainfall measurements, spatial drainage area characteristics (e.g., area, slope)			
<b>Data input type</b>	Quantitative			
<b>Data collection frequency</b>	Annually; at minimum, before and after NBS implementation			
<b>Level of expertise required</b>	High – requires ability to apply hydrologic models and assess the output			

<b>Synergies with other indicators</b>	Direct relation to <i>Height of flood peak</i> and <i>Time to flood peak</i> indicators
<b>Connection with SDGs</b>	SDG 11 Sustainable cities and communities
<b>Opportunities for participatory data collection</b>	No opportunities identified
<b>Additional information</b>	
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### 3.14 Water Quality – general urban

**Project Name:** CONNECTING Nature (Grant Agreement no. 730222)

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Water quality – general urban	Water Management
<p><b>Description and justification</b></p>	<p>Run-off water in cities represents a threat to water quality by conveying high pollutant loads into receiving water bodies and ground water aquifers. NBS can help manage and improve urban water quality through settlement, filtration, bioretention and phytoremediation. Emerging techniques using remote sensing technology includes using high resolution satellite or airborne optical imagery (visible and infrared), DSM (Digital Surface Model) height information and existing building out- lines maps (footprints) to estimate the percentage of vegetated areas on building roofs and to identify potential green roof sites, providing municipalities with the opportunity to use this data for urban planning decisions in the field of climate modelling, drainage system calculation and biodiversity networks. Recent and planned launches of satellites with improved spectral and spatial resolution sensors should lead to greater use of remote sensing techniques to assess and monitor water quality parameters.</p> <p>Data on the water quality performance of nature-based solutions collected in these ways can be used to:</p> <ul style="list-style-type: none"> <li>• Quantify the benefits of NBS in terms of stormwater/waterway quality improvement;</li> <li>• Assess any negative impact on water quality of diverting rainwater through NBS;</li> <li>• Calculate total pollution loading being released from an NBS (when combined with flow rate calculations);</li> <li>• Assess compliance with Water Framework Directives;</li> </ul> <p>Provide easily accessible data to communities and decision-makers to change perceptions of SuDS.</p>
<p><b>Definition</b></p>	<p>Calculating/predicting the change in water quality caused by diverting rainfall or surface water flow through an NBS (e.g., green roof, tree pit, bioretention pond, rain garden, wet woodland, naturalised waterway, etc). Implementing an NBS can result in a positive or negative impact on water quality. This is dependent upon: the quality of water entering the system, the type of NBS, the age of NBS, and the water quality parameters being investigated. Both</p>

	<p>positive and negative impacts of NBS on water quality are of relevance for this indicator. Remote sensing and earth observation approaches are only generally used to provide background/mapping data that can be fed into water quality modelling.</p>
<p><b>Strengths and weaknesses</b></p>	<p><b>Applied methods:</b> Robustness of evidence depends upon the precision and accuracy of the method adopted. Frequency and design of sampling is also linked to the strength of evidence. For example, regular sampling may provide long-term and seasonal patterns but may miss significant short-term events such as 'first flush' of urban areas following long dry periods.</p> <p><b>EO/RS methods:</b> Methods can provide robust data, but the range of water quality parameters that EO/RS can provide is limited.</p>
<p><b>Measurement procedure and tool</b></p>	<p><i>Applied/participatory methods:</i></p> <p>Basic measurements of water quality associated with Nbs have included:</p> <ul style="list-style-type: none"> <li>• NO<sub>3</sub>, NO<sub>2</sub> and NH<sub>3</sub> (<a href="#">Payne et al., 2014</a>; <a href="#">Batalini de Macedo et al. 2019</a>)</li> <li>• Phosphorus (<a href="#">Bratieres et al. 2008a</a>)</li> <li>• Heavy metals (<a href="#">Blecken et al. 2011</a>; <a href="#">Batalini de Macedo et al. 2019</a>)</li> <li>• Suspended/Sedimentary solids (<a href="#">Hatt et al 2008</a>; <a href="#">Batalini de Macedo et al. 2019</a>, <a href="#">Fowdar et al. 2017</a>)</li> <li>• Micropollutants (such as hydrocarbons and pesticides) (<a href="#">Zhang et al. 2014</a>)</li> <li>• Colour (<a href="#">Batalini de Macedo et al. 2019</a>)</li> <li>• Turbidity (<a href="#">Batalini de Macedo et al. 2019</a>)</li> <li>• Chemical Oxygen Demand (<a href="#">Batalini de Macedo et al. 2019</a>; <a href="#">Leroy et al. 2016</a>)</li> <li>• Biological Oxygen Demand (<a href="#">Fowdar et al. 2017</a>; <a href="#">Leroy et al. 2016</a>)</li> <li>• Pathogens (<a href="#">Bratieres et al. 2008b</a>)</li> <li>• Hydrocarbons (<a href="#">Hong et al. 2006</a>)</li> <li>• Total organic carbon (TOC) and dissolved organic carbon (DOC) (<a href="#">Fowdar et al. 2017</a>)</li> </ul> <p>Choice of parameter to measure should be related to issues of water pollution, the type of plant species and substrates used in the bioretention process, physio-chemical processes, and the desired quality of water at the end of processing (<a href="#">Dagenais et al. 2018</a>; <a href="#">Payne et al. 2018</a>, <a href="#">Batalini de Macedo et al. 2019</a>).</p> <p>Sampling can be done using in-situ stormwater sampling equipment (e.g., Teledyne ISCO 6712/7400 (<a href="#">Hong et al.</a></p>

[2006](#)), ISCO GLS auto-sampler ([Lucke and Nichols 2015](#)), ISCO Model 6712 Portable Sampler (Stagge et al. 2012)). This allows continuous and simultaneous sampling. Where this is not possible, or is prohibited by cost, v-notch weirs installed to monitor flow rate can be used to create a reservoir that can be sampled using a manual sampling technique ([Hong et al. 2006](#)). Alternatively, artificial drain/reservoir features can be incorporated into the NbS design from which water samples can be collected ([Leroy et al. 2016](#)). Laboratory analysis of each parameter is then carried out based on standardised analytical methods (e.g., Standard Methods for Examination of Water and Wastewater (APHA, 2015)).

An alternative, and more participatory method of monitoring water quality can be achieved through the use of biological indicators to monitor moving or still waterbodies. An example of this is the Biological Monitoring Working Party (BMWP) scoring system ([Armitage et al. 1983](#)) or adapted versions of this protocol (e.g., [Romero et al. 2017](#)). Samples are typically collected by kick sampling or surber sampling ([Everall et al. 2017](#)), providing opportunities for community engagement (including as part of school curricular activities). Wetland plants have also been used as biological indicators of water chemistry in wetland areas (US EPA 2002).

Simulated storm events with artificially created water pollution can be used as a mechanism to validate performance of NbS ([Lucke and Nichols 2015](#)). This is of particular value to ensure continuity of performance as the NbS ages/matures.

#### *Remote sensing/Earth observation methods:*

Remote sensing and earth observation approaches are only generally used to provide background/mapping data that can be fed into water quality modelling. However, some remote sensing techniques are emerging. Methods for delivering this include:

##### **a) In general:**

The remote sensing technology uses high resolution satellite or airborne optical imagery (visible and infrared), DSM (Digital Surface Model) height information and existing building out- lines maps (footprints) to estimate the

	<p>percentage of vegetated areas on building roofs and to identify potential green roof sites.</p> <p>The new remote sensing technology provides municipalities with the opportunity to use this data for urban planning decisions in the field of climate modelling, drainage system calculation and biodiversity networks.</p> <p>According to <a href="#">Ritchie et al. (2003)</a>, remote sensing techniques can be used to monitor water quality parameters (i.e., suspended sediments (turbidity), chlorophyll, and temperature). Optical and thermal sensors on boats, aircraft, and satellites provide both spatial and temporal information needed to monitor changes in water quality parameters for developing management practices to improve water quality. Recent and planned launches of satellites with improved spectral and spatial resolution sensors should lead to greater use of remote sensing techniques to assess and monitor water quality parameters. Integration of remotely sensed data, GPS, and GIS technologies provides a valuable tool for monitoring and assessing waterways. Remotely sensed data can be used to create a permanent geographically located database to provide a baseline for future comparisons. The integrated use of remotely sensed data, GPS, and GIS will enable consultants and natural resource managers to develop management plans for a variety of natural resource management applications.</p> <p>In addition, <a href="#">Massoudieh et al. (2017)</a> developed a modelling framework to predict the water quality impacts of urban stormwater green infrastructure systems. Shi et al. 2017 demonstrated links between urban water quality and different landuse patterns that could be used to predict improvements in water quality.</p> <p>For further information, see:  <a href="#">Connecting Nature Environmental Indicator Metrics Review Report</a></p>
<p><b>Scale of measurement</b></p>	<p><b>Applied methods:</b> Implementation is typically on a component or site level. It can be scaled-up to much larger scales through replication. However, it is more typical to model the impacts of up-scaling once results have been obtained that can be fed into the model.</p> <p><b>EO/RS methods:</b> Typically used on medium/large scale monitoring as resolution of satellite imagery can create a barrier to monitoring smaller scale areas.</p>



<b>Data source</b>	
<b>Required data</b>	Required data will depend on selected methods, for further details on applied and earth observation/remote sensing metrics refer to <a href="#">Connecting Nature Environmental Indicator Metrics Review Report</a>
<b>Data input type</b>	Data input types will be depend on selected methods, for further details on applied or earth observation/remote sensing metrics refer to <a href="#">Connecting Nature Environmental Indicator Metrics Review Report</a>
<b>Data collection frequency</b>	Data collection frequency will be depend on selected methods, for further details on applied or earth observation/remote sensing metrics refer to <a href="#">Connecting Nature Environmental Indicator Metrics Review Report</a>
<b>Level of expertise required</b>	<p><b>Applied methods:</b> Some expertise required for installation of equipment and/or sampling methodology. Expertise required for sample analysis depends on the level of automation of the sampling equipment (e.g., in stream dataloggers carry out sample analysis automatically). Samples taken may require specialist analytical methods, these are typically carried out through an accredited laboratory. Data analysis/interpretation against statutory guidelines can be very basic once systems are in place.</p> <p><b>EO/RS methods:</b> Data processing expertise is needed.</p>
<b>Synergies with other indicators</b>	<p><b>Applied methods:</b> There are synergies in relation to measuring flowrates as such data is necessary for calculating total pollutant loads over time. BMWP scoring can be linked to biodiversity indicators. Improved water quality can have correlations with nature, health and social value of a waterway.</p> <p><b>EO/RS methods:</b> Synergies with other water management and blue space area indicators.</p>
<b>Connection with SDGs</b>	SDG3, SDG4, SDG6, SDG8-SDG12; SDG14-SDG17: Clean water supply; Links to environmental education; Clean water; Job creation; Social equality in relation to water quality; Sustainable urban development; More sustainable water management; Improved water quality (for life below water); Improved water quality (for life on land); Environmental Justice; Opportunities for collaborative working
<b>Opportunities for participatory data collection</b>	<b>Applied methods:</b> Opportunities are available for a participatory process, particularly in relation to carrying out visual inspection of water (e.g., in relation to combined sewage overflow occurrences and water sampling (Farnham et al. 2017; Jollymore et al. 2017). Water quality analysis can be linked to local schools/universities, especially through schemes that use BMWP methodologies to monitor

water quality in waterways. Automated dataloggers offer less opportunity for such participation with participation limited to observing and processing the data produced. There are also opportunities for stewardship of equipment or nature-based solution, etc.

**EO/RS methods:** Limited opportunities for participation

## Additional information

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### 3.15 Total Suspended Solids (TSS) content

**Project Name:** CLEVER Cities (Grant Agreement no. 776604), GrowGreen (Grant Agreement no. 730283) and UNaLab (Grant Agreement no. 730052)

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TSS content	Water Management
<b>Description and justification</b>	Total Suspended Solids (TSS) are solids in water that can be trapped by a filter. TSS can include a wide variety of material and can have adsorbed pollutants. High concentrations of suspended solids can affect the health and productivity of the aquatic life. TSS and turbidity are simple indicators of water quality. Sources of TSS include, e.g., sediment runoff from agricultural fields, logging activities, construction sites, roadways, waste discharge, or

	<p>excessive algal growth. The TSS content often increases sharply during and immediately following a rainfall event. The EU Freshwater Fish Directive (2006/44/EC) recommends <math>\leq 25</math> mg/L TSS for salmonid and cyprinid fish health (European Parliament, 2006), whilst the concentration of TSS in wastewater treatment plant effluents is limited to <math>\leq 35</math> mg/L by Wastewater Directive 91/271/EEC (European Parliament, Council of the European Union, 1991).</p>
<b>Definition</b>	<p>Total suspended solids (TSS) or turbidity (% , mg/L and total; units dependent upon measurement technique). A measure of the suspended solids in wastewater, effluent, or water bodies, determined by tests for "total suspended non-filterable solids".</p>
<b>Strengths and weaknesses</b>	<ul style="list-style-type: none"> <li>+ Simple evaluation</li> <li>+ In turbidity measurements, Secchi disk is very commonly used visual method because it is easy to use, inexpensive, and relatively accurate. The turbidity meter method is very accurate</li> <li>- Laboratory measurement of TSS directly quantifies the amount of fine particulate material suspended in water but is relatively time-intensive.</li> <li>- Time consuming TSS measurements, non-continuous compared to turbidity</li> </ul>
<b>Measurement procedure and tool</b>	<p>Total suspended solids (TSS) are typically quantified in the laboratory using a gravimetric process, yielding TSS measurement in units of mass per volume (e.g., mg/L or ppm). Measurement of TSS involves filtration of a water sample followed by drying and weighing of the particulates removed. Simply, this means anything that is captured by filtering the sample aliquot through a specific pore size filter. A measured volume (no more than 1 L) of sample is passed through a prepared, pre-weighed filter paper. The filter is dried at <math>104 \pm 1^\circ\text{C}</math>. After drying, the filter is reweighed and the TSS is calculated.</p> <p>A semi-quantitative, rapid assessment of TSS can be accomplished by evaluating sample turbidity, a measure of the relative transparency of a water sample. Turbidity measurements rely on comparison of light scattering with standard solutions (turbidity meter) or visual assessment (Secchi disk, transparency tube). Turbidity meters use a light beam with defined characteristics to provide a semi-quantitative measure of the particulates present in the water, providing an integrated measure of light scattering and absorption. The measurement is provided in nephelometric turbidity units (NTU). Turbidity (in NTU) can</p>

	<p>be directly related to TSS (in mg/L) via creation of a standard curve (TSS versus turbidity) for a given location/type of fine particulate material.</p> <ul style="list-style-type: none"> <li>• Measuring turbidity <i>in-situ</i>: <ul style="list-style-type: none"> <li>○ Secchi disk, which is lowered into the water and the level where the disk disappears is registered.</li> <li>○ Turbidity meter consists of a light source that illuminates a water sample and a photoelectric cell that measures the intensity of light scattered at a 90° angle by the particles in the sample.</li> <li>○ Transparency tube is a clear, narrow plastic tube marked in units with a light and dark pattern painted on the bottom. Water is poured into the tube until the pattern disappears, and the depth is recorded.</li> </ul> </li> </ul>
<b>Scale of measurement</b>	Plot scale to district scale
<b>Data source</b>	
<b>Required data</b>	TSS or turbidity measurement data
<b>Data input type</b>	Quantitative and semi-quantitative
<b>Data collection frequency</b>	Daily, weekly, monthly or annually
<b>Level of expertise required</b>	Low to moderate
<b>Synergies with other indicators</b>	Synergies with the other water quality indicators in the <i>Water management</i> indicator group
<b>Connection with SDGs</b>	SDG 6 Clean water and sanitation, SDG 13 Climate action, SDG 14 Life below water
<b>Opportunities for participatory data collection</b>	Participatory data collection for turbidity is possible under supervision
<b>Additional information</b>	
<b>References</b>	<p>ASTM. (2018). <i>ASTM D5907-18, Standard Test Methods for Filterable Matter (Total Dissolved Solids) and Nonfilterable Matter (Total Suspended Solids) in Water</i>. ASTM International, West Conshohocken, PA.</p> <p>Orhel, R.L., &amp; Register, K.M. (2006). <i>Volunteer Estuary Monitoring. A Methods Manual</i>. 2<sup>nd</sup> edition. United States Environmental Protection Agency, Washington, D.C.</p> <p>International Organization for Standardization (ISO). (2016). <i>International Standard ISO 7027-1:2016 Water quality —</i></p>

*Determination of turbidity – Part 1: Quantitative methods.*  
International Organization for Standardization, Geneva.  
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*Determination of turbidity – Part 2: Semi-quantitative*  
*methods for the assessment of transparency of waters.*  
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### 3.16 Nitrogen and phosphorus concentration or load

**Project Name:** UNaLab (Grant Agreement no. 730052)

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Water Quality: Nitrogen and phosphorus concentration or load	Water Management
<p><b>Description and justification</b></p>	<p>Nutrients, including nitrogen (N) and phosphorus (P), can have significant impact on water quality, including effects on plant growth, oxygen concentration, water clarity, and sedimentation rates. Some major anthropogenic sources of nutrients are agricultural and industrial emissions, discharged wastewater and atmospheric deposition. Nitrogen and phosphorus are present in water in many different forms, or as many different chemical species. The forms of N and P that are quantified can include some or all of the following:</p> <ul style="list-style-type: none"> <li>• <u>Nitrogen</u>: total N (<math>N_{tot}</math>), total Kjeldahl N (TKN), dissolved organic N (DON), nitrate (<math>NO_3^-</math>), nitrite (<math>NO_2^-</math>) and ammonia/ammonium (<math>NH_3/NH_4^+</math>)</li> <li>• <u>Phosphorus</u>: total P (<math>P_{tot}</math>), acid-hydrolysable P (AHP), orthophosphate (<math>PO_4^{3-}</math>)</li> </ul>
<p><b>Definition</b></p>	<p>Nitrogen and phosphorus in surface water and/or groundwater (%), expressed as total annual N or P load and/or reduction of maximum annual concentration)</p>
<p><b>Strengths and weaknesses</b></p>	<p>+ Laboratory analyses are accurate but can be quite costly. A full suite of analyses can be done for multiple chemical species of N and P.</p> <p>+ Ion selective electrodes (ISEs) are less expensive and easier to use alternative. Whilst ISEs for various N species (<math>NO_2^-</math>, <math>NO_3^-</math>, <math>NH_3/NH_4^+</math>) are readily available from multiple suppliers,</p>

	<p>ISEs for phosphate are less common. ISEs have a potential for permanent installation at a given sampling point.</p> <p>- Test kits obtain a rapid result, but are in general less accurate than analyses performed in an accredited laboratory. Photometers are generally quite accurate but can be expensive to purchase and maintain. Test kits based on colour comparison, either of test strips or solutions, are relatively less costly but can have limited accuracy at low nutrient concentrations</p>
<b>Measurement procedure and tool</b>	<p>Different nitrogen and phosphorus species can be quantified in a water sample either in the field, using a test kit or ion selective electrode (ISE), or via laboratory analyses. Laboratory analyses can be done for multiple chemical species of N and P.</p> <p>Ion selective electrodes are analogous to a pH electrode and are used in much the same way as a pH electrode (pH electrodes are essentially ion selective electrodes that are sensitive to the H<sup>+</sup> ion) ISEs have a potential for permanent installation at a given sampling point. It is possible to program a data logger connected to an <i>in-situ</i> ISE to measure and record a value at a prescribed frequency.</p> <p>Test kits are usually used on site (in the field). Test kits typically involve the addition of chemical reagents to a water sample and yield results based on test strip colour comparison, solution colour comparison to a colour wheel or colour chart, or measurement with a photometer. The spectrophotometer measures the quantity of a chemical based on its characteristic absorption spectrum.</p>
<b>Scale of measurement</b>	Plot scale to district scale, depending on location of sampling point
<b>Data source</b>	
<b>Required data</b>	Measurement data of a water sample
<b>Data input type</b>	Quantitative
<b>Data collection frequency</b>	Daily, weekly, monthly or annually
<b>Level of expertise required</b>	Low to moderate
<b>Synergies with other indicators</b>	Synergies with the other water quality indicators in the <i>Water management</i> indicator group
<b>Connection with SDGs</b>	SDG 13 Climate action, SDG 14 Life below water



<b>Opportunities for participatory data collection</b>	Participatory data collection possible with test kits and ion selective electrodes under supervision
<b>Additional information</b>	
<b>References</b>	<p>EPA method 300.1: Determination of inorganic anions in drinking water by ion chromatography;  <a href="https://www.epa.gov/sites/production/files/2015-06/documents/epa-300.1.pdf">https://www.epa.gov/sites/production/files/2015-06/documents/epa-300.1.pdf</a></p> <p>ISO 29441:2010:  Water quality — Determination of total nitrogen after UV digestion — Method using flow analysis (CFA and FIA) and spectrometric detection, <a href="https://www.iso.org/standard/45480.html">https://www.iso.org/standard/45480.html</a></p> <p>ISO 15681-1:2003  Water quality — Determination of orthophosphate and total phosphorus contents by flow analysis (FIA and CFA) — Part 1: Method by flow injection analysis (FIA),  <a href="https://www.iso.org/obp/ui/#iso:std:iso:15681:-2:ed-2:v1:en">https://www.iso.org/obp/ui/#iso:std:iso:15681:-2:ed-2:v1:en</a></p> <p>ISO 15681-2:2018  Water quality — Determination of orthophosphate and total phosphorus contents by flow analysis (FIA and CFA) — Part 2: Method by continuous flow analysis (CFA),  <a href="https://www.iso.org/standard/66474.html">https://www.iso.org/standard/66474.html</a></p> <p>Orhel, R.L., &amp; Register, K.M. (2006). Volunteer Estuary Monitoring. A Methods Manual. Second edition. Washington, D.C: United States Environmental Protection Agency.</p> <p>Reedyk, S., &amp; Forsyth, A. (2006). <i>Using field chemistry kits for monitoring nutrients in surface water</i>. Publication number PRO-121-2006-1. Ottawa, Ontario, Canada: Agriculture and Agri-Food Canada PFRA. Retrieved from  <a href="http://pfra.ca/doc/Water%20Quality/Water%20Quality%20Protection/using_field_chem_kits_final.pdf">http://pfra.ca/doc/Water%20Quality/Water%20Quality%20Protection/using_field_chem_kits_final.pdf</a></p>

### 3.17 Metal concentration or load

**Project Name:** CLEVER Cities (Grant Agreement no. 776604), GrowGreen (Grant Agreement no. 730283) and UNaLab (Grant Agreement no. 730052)

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Water Quality: Metal concentration or load	Water Management
<p><b>Description and justification</b></p>	<p>Metals and metalloids (herein referred to simply as metals) are ubiquitous in the natural environment and can potentially accumulate to toxic levels for the aquatic environment and humans as metals do not degrade with time. As such, metals can have a significant impact on water quality and its fit-for-purpose use. Natural sources of metals include weathering of geologic materials (rocks and soil) and volcanic activity. The primary reservoir of metals is geological substrate. Human activity has greatly accelerated natural biogeochemical cycles, resulting in anthropogenic emissions of metals to the atmosphere one to three orders of magnitude greater than natural fluxes. Anthropogenic sources of metals include point sources such as mining and industrial activities, and non-point sources such as fossil fuel combustion and agricultural activities. Stormwater may transport heavy metals from industries, municipalities and urban areas at different quantities, which are accumulated in soil, sediments and water bodies. Removal can be achieved by appropriately designed NBS.</p> <p>Some of the more common metal pollutants are: aluminium (Al), arsenic (As), barium (Ba), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), molybdenum (Mo), nickel (Ni), lead (Pb) and mercury (Hg), selenium (Se), vanadium (V) and zinc (Zn).</p>
<p><b>Definition</b></p>	<p>Metal pollutants in surface water and/or groundwater (% , expressed as total annual metal pollutant load and/or reduction of maximum annual concentration).</p> <p>(Concentration of heavy metals before NBS treatment - Concentration of heavy metals after NBS treatment)/ Concentration of heavy metals before NBS treatment)*100</p>
<p><b>Strengths and weaknesses</b></p>	<p>+ ICP analyses are highly precise and accurate to very low concentrations</p>

	<ul style="list-style-type: none"> <li>- ICP analyses can be quite costly and with the high number of metals (Cd, Cr, Pb, Hg, Ni, Zn, Cu...) some of which could be at very low concentration levels, this can add to the expense.</li> <li>- There is usually a significant delay between the time of sample collection and receipt of water quality data from the laboratory</li> <li>+ Test kits and ion selective electrodes (ISEs) can provide rapid results</li> <li>+ ISEs can be installed in-situ to take measurements at regular intervals</li> <li>- A separate kit or ISE is required for each element of interest, and the limit of detection for a given element of interest may be substantially higher than the respective accredited laboratory analysis technique</li> <li>- Analysis of individual metals using field test kits can be time-intensive and/or require trained personnel to conduct the tests</li> </ul>
<p><b>Measurement procedure and tool</b></p>	<p>Metals in water samples are typically quantified in an accredited laboratory using a suite of standardised analyses. Ion-coupled plasma spectrophotometry (ICP) coupled with atomic emission spectrometry (MS), with or without pre-treatment/pre-concentration, is a well-recognised analytical method for the quantification of trace metals in waters. Multiple elements can be analysed from a single sample. Methods may vary depending on the water matrix and metals to be analysed, but generally the method comprises the following steps:</p> <ul style="list-style-type: none"> <li>• Sample preparation which may include weighing of the sample, solubilisation of the solids with acids with/without heat (for total recovery analysis), separation of undissolved material</li> <li>• Calibration of the equipment</li> <li>• Sample analysis</li> </ul> <p>The nature of ICP analyses means that the analysed samples represent a single point in time (the time at which the sample was collected), and metal concentrations may vary substantially in urban waters due to the contribution of run-off from urban surfaces.</p> <p>Field test kits are available for on-site testing of some metals (e.g., As, Cd, Cu, Pb, Mo, etc.) whilst other metals can be detected using an ion-selected electrode (ISE; e.g., Cd, Pb, Zn, etc.). Field test kits vary greatly and range from semi-quantitative paper test strips for multiple metals, to quantitative colourimetric-type analyses. Some field test kits may involve the use of portable laboratory</p>

	equipment such as a photometer, fluorometer or similar. With ISEs there is a potential to install a testing unit in-situ to take measurements at regular intervals and save results to a data logger or upload to a central data repository.
<b>Scale of measurement</b>	Plot scale to district scale, depending on location of sampling point for concentrations ranging from ng/L to mg/L
<b>Data source</b>	
<b>Required data</b>	Water samples. Relatively small sample volume is required (typically 100 mL or less)
<b>Data input type</b>	Quantitative and semi-quantitative
<b>Data collection frequency</b>	Daily, weekly, monthly or annually
<b>Level of expertise required</b>	Low to Moderate for sampling High for analysis
<b>Synergies with other indicators</b>	Synergies with the other water quality indicators in the <i>Water management</i> indicator group
<b>Connection with SDGs</b>	SDG 6 Clean water and sanitation, SDG 13 Climate action, SDG 14 Life below water
<b>Opportunities for participatory data collection</b>	Participatory data collection possible with test kits and ion selective electrodes under supervision
<b>Additional information</b>	
<b>References</b>	<p>Chaturvedi, A., Bhattacharjee, S., Mondal, G.C., Kumar, V., Singh, P.K., &amp; Singh, A.K. (2019). Exploring new correlation between hazard index and heavy metal pollution index in groundwater. <i>Ecological Indicators</i>, 97, 239-246.</p> <p>Chaturvedi, A., Bhattacharjee, S., Singh, A.K., &amp; Kumar, V. (2018). A new approach for indexing groundwater heavy metal pollution. <i>Ecological Indicators</i>, 87, 323-331.</p> <p>European Parliament, Council of the European Union. (2000). EU Water Framework Directive: Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 Establishing a Framework for Community Action in the Field of Water Policy. Retrieved from <a href="http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02000L0060-20140101">http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02000L0060-20140101</a></p> <p>International Organization for Standardization (ISO). 2004. <i>International Standard ISO 17294-1:2004 Water quality – Application of inductively coupled plasma mass spectrometry (ICP-MS) – Part 1: General guidelines</i>. International Organization for Standardization, Geneva.</p> <p>International Organization for Standardization (ISO). 2016. <i>International Standard ISO 17294-2:2016 Water quality – Application of inductively coupled plasma mass spectrometry</i></p>

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### 3.18 Total faecal coliform bacteria

**Project Name:** UNaLab (Grant Agreement no. 730052) and PHUSICOS (Grant Agreement no. 776681)

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Total faecal coliform bacteria in NBS effluents	Water Management
<p><b>Description and justification</b></p>	<p>Faecal coliform bacteria are a subgroup of a larger total coliform group referring to the Gram-negative, rod-shaped bacteria. Faecal coliform bacteria denote a group of thermotolerant coliform organisms, optional aerobic or anaerobic, which grow at <math>44 \pm 0.5</math> °C and ferment lactose to produce acid and gas (Bartram &amp; Pedley, 1996; Doyle &amp; Erickson, 2006). Although coliform bacteria are easy to detect, their presence does not imply the faecal contamination due to the natural occurrence of some faecal coliform organisms of non-faecal origin. Thus, the pathogenic strains of <i>Escherichia coli</i> (<i>E. coli</i>) are usually analysed to determine the sanitary contamination of water</p>

	(ISO, 2014). Presence of faecal coliform bacteria in the natural waters may indicate the faecal contamination and degradation of the water bodies originating from diffuse sources such as urban runoff and transport from sewer overflows (Davies et al., 1995; Davies & Bavor, 2000).
<b>Definition</b>	Observed number of faecal coliform colony units determined by direct counting (Colony Forming Unit (CFU)/100 mL or CFU/100 g) or most probable number (MPN) methods (MPN/100 mL or MPN/g)
<b>Strengths and weaknesses</b>	+ Almost always implies the faecal contamination of water + Standardized methodology for analyses - Analyses require expert knowledge and judgement
<b>Measurement procedure and tool</b>	<p>a. Membrane filtration and direct counting</p> <p>The traditional way of evaluating the water samples for bacteria is the membrane filtration method. First, the water sample is filtered through a membrane, then the bacteria are cultured on an agar medium in a Petri dish and incubated at a specified temperature for a specified period of time depending on the type of bacteria analysed. Later, the number of the target organisms in the sample is calculated.</p> <p>The background bacterial growth may inhibit the enumeration of coliform bacteria, so this method is not deemed suitable for shallow and surface waters.</p> <p>b. Most probable number (MPN) method</p> <p>MPN is a statistical method used for enumeration of the viable target organisms by sequential inoculation and incubation in a liquid medium in ten-fold dilutions. Several assumptions must be made when using the MPN method, such as assuming the random distribution of the organisms in the sample (implying that no bacterial clustering and repelling is present), and assuming that the tubes will produce detectable growth.</p> <p>The advantages of the MPN method include the possibility for adjustment of the accuracy of the results when increasing the number of tubes per dilution, and larger sample size than in the plate count method.</p> <p>The MNP method is suitable for all types of water.</p>
<b>Scale of measurement</b>	Plot scale
<b>Data source</b>	
<b>Required data</b>	Microbiological analyses of water
<b>Data input type</b>	Quantitative

<b>Data collection frequency</b>	At minimum before and after NBS implementation
<b>Level of expertise required</b>	High – requires familiarity with the laboratory practices and expertise for conducting the microbiological analyses and evaluating the outcomes
<b>Synergies with other indicators</b>	Together with other <i>Water Management</i> indicators determines the overall status of water quality in an area
<b>Connection with SDGs</b>	SDG 11 Sustainable cities and communities, SDG 13 Climate action, SDG 14 Life below water
<b>Opportunities for participatory data collection</b>	Participatory data collection is possible under direct qualified staff supervision
<b>Additional information</b>	
<b>References</b>	<p>Bartram, J. &amp; Pedley, S. (1996). <i>Chapter 10 – Microbiological Analyses</i>. In: Bartram, J. &amp; Ballance, R. (Eds.). <i>Water quality monitoring: a practical guide to the design and implementation of freshwater quality studies and monitoring programmes</i>. CRC Press. Retrieved from: <a href="https://www.who.int/water_sanitation_health/resourcesquality/wqmchap10.pdf">https://www.who.int/water_sanitation_health/resourcesquality/wqmchap10.pdf</a></p> <p>Davies, C. M., &amp; Bavor, H. J. (2000). The fate of stormwater-associated bacteria in constructed wetland and water pollution control pond systems. <i>Journal of Applied Microbiology</i>, 89(2), 349-360.</p> <p>Davies, C. M., Long, J. A., Donald, M., &amp; Ashbolt, N. J. (1995). Survival of fecal microorganisms in marine and freshwater sediments. <i>Applied and Environmental Microbiology</i>, 61(5), 1888-1896.</p> <p>Doyle, M. P., &amp; Erickson, M. C. (2006). Closing the door on the fecal coliform assay. <i>Microbe</i>, 1(4), 162-163.</p> <p>International Organization for Standardization (ISO). (2014). <i>International Standard ISO 9308-1:2014: Water quality – Enumeration of Escherichia coli and coliform bacteria – Part 1: Membrane filtration method for waters with low bacterial background flora</i>. International Organization for Standardization, Geneva.</p> <p>International Organization for Standardization (ISO). (2012). <i>International Standard ISO 9308-2: Water quality – Enumeration of Escherichia coli and coliform bacteria – Part 2: Most probable number method</i>. International Organization for Standardization, Geneva.</p> <p>International Organization for Standardization (ISO). (2012). <i>International Standard ISO 9308-3: Water quality – Detection and enumeration of Escherichia coli and coliform bacteria – Part 3: Miniaturized method (Most Probable Number) for the detection and enumeration of E. coli in</i></p>

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*This Evaluating the Impact of Nature-based Solutions: Appendix of Methods accompanies the Handbook for Practitioners for evaluating the impact of nature-based solutions (NBS). The overarching objective of the Handbook and this accompanying Appendix of Methods is to provide standardised guidance and methods to aid the selection and implementation of indicators to assess impacts of NBS, and, over time, establish a robust European evidence base on NBS performance and impact. In order to compare impacts of different types of NBS, implemented in different contexts, and to draw valid, evidence-based conclusions regarding NBS impact, similar indicators, methods, and types of measurement are needed. The Evaluating the Impact of Nature-based Solutions: Handbook for Practitioners and accompanying Appendix of Methods identifies indicators and briefly details methodologies to assess impacts of nature-based solutions across 12 societal challenge areas: Climate Resilience; Water Management; Natural and Climate Hazards; Green Space Management; Biodiversity; Air Quality; Place Regeneration; Knowledge and Social Capacity Building for Sustainable Urban Transformation; Participatory Planning and Governance; Social Justice and Social Cohesion; Health and Well-being; and, New Economic Opportunities and Green Jobs.*

*Evaluating the Impact of Nature-based Solutions: Appendix of Methods provides a brief description of each indicator and recommends appropriate methods to measure specific impacts, along with guidance for end-users about the appropriateness, advantages and drawbacks of each method in different local contexts. As such, it is intended to guide the implementation of selected indicators to assess NBS performance and impact.*

*Studies and reports*

