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A Framework for Assessing Benefits of Implemented Nature-Based Solutions

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Abstract: Nature-based solutions (NBS) are solutions that can protect, sustainably manage, and restore natural or modified ecosystems in urban and rural areas, while providing many benefits and co-benefits including stormwater mitigation, biodiversity enhancement, and human well-being. As such, NBS have the potential to alleviate many of the environmental, social, and economic issues that we face today. Grey infrastructure, such as lined trenches and catch basins, pipes, and concrete dikes are frequently used for stormwater management and flood protection, but they do not provide many of the co-benefits that are common with NBS. Grey infrastructure is designed to quickly collect and remove rainwater, whereas NBS keep rainwater where it falls, and where it can be used by the environment. Many stakeholders lack knowledge of the capabilities and benefits of NBS, and as a result, they continue to rely on grey infrastructure in their projects. When information is made available on the benefits and how they can be quantitatively measured, it is hoped that NBS will be promoted to a mainstream infrastructure choice. A valuable way to quantify and highlight the benefits of NBS is by using an evaluation framework. There are several evaluation frameworks that qualitatively assess the potential benefits of possible NBS, however there is a need for quantitative frameworks that can assess the actual benefits (or performance) of implemented (or existing) NBS. This article presents an evaluation framework that aims to quantify the benefits and co-benefits of implemented NBS. The framework involves five main steps: (1) selection of NBS benefit categories, (2) selection of NBS indicators, (3) calculation of indicator values, (4) calculation of NBS grade, and (5) recommendations. The outcome of the framework is a single numerical grade that reflects the benefit functioning for an NBS site and values for each performance indicator. This information may be used by decision makers to determine their budget allocations to expand or construct a new NBS site, to update maintenance plans that will improve the benefits of that site, to set up programs to monitor the NBS benefits and co-benefits over time, and to schedule labour and resources for other NBS projects. The framework was tested and validated on a case study of NBS in Thailand. Through conversations with stakeholders and knowledge of the case study area, relevant categories and indicators were chosen. Using data and information obtained through various means, values for each indicator and the overall NBS grade were calculated. The values revealed which benefits were pronounced, those that were weak, and where improvements were required.

Keywords: nature-based solutions; evaluation framework; benefits; co-benefits; hydro-meteorological risk reduction

1. Introduction

Extreme weather events affected 60 million people worldwide in 2018; floods were responsible for 35.4 million deaths, storms traumatized 12.8 million people, wildfires caused billions of dollars in damage and were responsible for many deaths, landslides had detrimental impacts on 54,908 people, and droughts affected 9.3 million people [1]. It is no longer sufficient to respond to such disasters by implementing grey infrastructure alone.

Grey infrastructure options, such as pipes, are capable of conveying runoff from storms up to a specific size, for example, for a 1 in 10 year storm. Such rigid designs are not adaptable in an uncertain future climate. Furthermore, grey infrastructure removes stormwater from where it falls, making it inaccessible to the environment.

Nature-based solutions (NBS) are showing great potential in mitigating the effects of extreme weather events. NBS can slow and store stormwater which reduces downstream flooding; they are flexible and adaptable solutions to hydro-meteorological risk, and have the added potential to provide a range of benefits and co-benefits [2,3]. NBS can also be used in combination with grey infrastructure, which are often referred to as hybrid measures [4,5]. Such measures can provide a wealth of benefits for people, the environment, and the economy.

Small-scale NBS, such as infiltration trenches and rain gardens, can benefit stormwater management by reducing runoff, flooding, and transport of pollutants [6]. Vegetated swales can slow the runoff and mitigate erosion and sediment transport processes [7,8]. NBS that incorporate ponds or wetlands can provide benefits of infiltration, water storage and reuse, evapotranspiration, and groundwater recharge (GWR) [9].

(RFR) project implemented several large-scale NBS measures along four rivers in the Netherlands. These solutions included floodplain creation, lowering of dikes, widening and deepening of rivers, and construction of high-water channels to make room for excess river water in rural areas thus preventing flooding in urban areas. The main benefits of the RFR were flood mitigation, increase of recreation potential, and enhancement of the environment and aesthetics along the rivers. There were also numerous co-benefits as a result of this project, including increased biodiversity, habitat, accessibility, and water storage [10].

NBS that incorporate vegetation like grasses, shrubs, and trees are capable of reducing heat, noise, water, soil, and air pollution; they reduce waterborne illnesses, respiratory diseases, and stress for people who have access to them [11]. NBS are more adaptable to different storm events and can save millions of dollars when compared to implementation of grey infrastructure alone [12]. NBS with water storage and reuse capabilities can increase agriculture production and incomes in farming communities [13,14].

Overall, the benefits and co-benefits of implemented NBS can be observed in different domains and contexts, but systematic evaluation frameworks that can assess their full potential (as well as their possible side effects) are still lacking [15]. Such frameworks are needed in order to quantify the benefits so that decision makers have a better understanding of their advantages and disadvantages. There are several existing frameworks that can be found in the literature, most of them aim to evaluate potential benefits of future NBS, like the World Bank principles and implementation guidance framework [14]. Others focus on hydro-meteorological benefits [16]; there are a few frameworks that address the evaluation of implemented NBS, but these provide only qualitative assessments [17]. Hence, a framework for quantitative evaluation of implemented NBS is needed and this paper provides a contribution in this direction.

A recent review of NBS research revealed many gaps in the existing knowledge base [14]. The findings show that more investigations are required on the assessment of large scale NBS, hybrid measures that combine large and small scale NBS, and catchment scale NBS. Many methods were identified that are used to assess the benefits of NBS; these are hydrological and hydraulic modelling, water balance, rainfall runoff estimates, cost-benefit analysis, life cycle costing, and multi-criteria analysis. It is recommended that these methods be combined with interviews and fieldwork so that qualitative and quantitative benefits may be assessed [14].

Many stakeholders are uncertain about the performance and reliability of NBS [18], the present paper fills some of these gaps in the NBS knowledge base. The framework can be applied to urban and rural, large and small scale, hybrid, and catchment scale NBS, and it proposes a combination of several methods to assess both qualitative and quantitative benefits while integrating stakeholder's preferences.

The River Health Index (RHI) [19], which assesses the health of rivers and their ecosystems in Thailand, represents an important aspect in the proposed framework. The present framework assigns a grade to an existing NBS by assessing each individual benefit through various methods and stakeholder input. It aims to provide a systematic evaluation of the benefits and their relative effectiveness in comparison to the same situation without NBS. The output shows where improvements are possible and can help farmers to improve their resilience to climate change, their livelihoods, and the quality of life for their communities. The framework output also provides valuable information about NBS benefits and co-benefits as well as their advantages to support academics, water managers, and planners when studying, promoting, and implementing NBS technologies. The framework was applied to an NBS case study in the Rangsit canal area of Thailand.

2. Proposed Framework Overview

The framework proposed here was developed from other relevant frameworks, the current knowledge base of different NBS technologies, their benefits and co-benefits, performance indicators, and practical experiences. It also reflects on some important discussions with the key stakeholders in the case study area. The following sections describe the framework steps and its application.

2.1. Framework Steps

The framework proposed here takes the approach of the RECONECT [20] project which builds from the challenges of the EC-funded EKLIPSE [17] project; these are combined into three categories, namely water, nature, and people, and form the foundation for evaluating and comparing sites with and without NBS. It is important to note that the two sites compared should be alike in most aspects except for the presence of the NBS so that a meaningful comparison can be made. For example, the sites should have the same water, nature, and people related features such as climate, rainfall, water supply, rivers, land use type, culture, etc. If the sites are alike then the differences in the benefits are assumed to be the result of the NBS performance. The schematic layout of the proposed framework is shown in Figure 1. After determining the requirements of the stakeholders and becoming familiar with the case study area, the five steps in the framework can be followed to determine the performance and benefits of NBS.

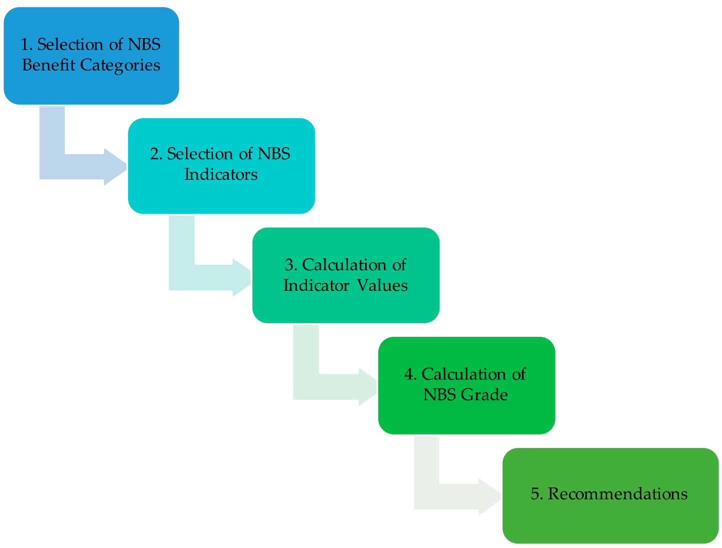

Figure 1. Framework overview.

2.1.1. Step 1: Selection of Benefit Categories

The benefits of NBS are categorized as water (W), nature (N), or people (P) related. This classification was adopted from the RECONECT project, where the main focus is on hydro-meteorological, or weather-related water benefits [20]. The water related benefits are directly associated with water, and include flood mitigation, drought and flood resilience, water storage and reuse, and groundwater and surface water quality. The nature related benefits are associated with the environmental features of soil, air, and vegetation, and include infiltration, biodiversity, and soil quality. The people related benefits include cultural, education, recreation, and economics.

Depending on the needs of stakeholders, and the relevance to the case study NBS, one, two, or all three of the categories may be selected for further analysis.

2.1.2. Step 2: Selection of Indicators

Selection of indicators is accomplished through stakeholder conversations and for each benefit category, select the indicators of interest and relevance from Tables S1–S3 in Supplementary Materials. Every benefit in different categories is represented by an indicator. Certainly, not all indicators can be applicable to each case.

Tables S1–S3 provide a description of each indicator and guidance on how to select the appropriate ones for a specific case study NBS. The list of NBS referred to in these tables is not exhaustive and the framework can be equally applied to other NBS.

2.1.3. Step 3: Calculation of Indicator Values

For each indicator selected in Step 2, a numerical value will be calculated to determine its performance. Equations can be found for indicators in Supplementary Materials; every equation requires data specific to each indicator. The data may be collected through interviews, literature searches, field investigation and measurements, numerical modelling, remote sensing, etc. The benefits can be either qualitative or quantitative and the final result is expressed in a numerical value.

The equations provided in Supplementary Materials aim to compare the variables of Area A (the case study area with the NBS) with those of Area B (the comparison area without NBS or the case study area before implementation of the NBS). For example, the variable for the indicator biodiversity is the number of species in the area.

Indicators may have a positive effect on the environment, such as biodiversity (number of species), or a negative effect, like water quality (or increased level of pollution). For the biodiversity indicator to have a high value, the number of species in Area A must be much higher than in Area B, and this is referred to as a positive effect (Equation (1)). For the water quality indicator to have a high value, the level of pollution must be much higher in Area B than in Area A and this is referred to as a negative effect (Equation (2)). Indicator values that are close or the same for Area A and Area B imply that there are no differences in indicators, or NBS benefits.

Equations should be tested with hypothetical numbers to see if they result in the appropriate values. The difference between Area A and Area B parameters must be large to produce a high value and small to produce a low value. The higher the value of each indicator, the more pronounced the benefit will be in that area.

The equations used to determine the value for each indicator may be of the following types:

1. Percent change equation: the difference between Area A and Area B for indicator X.

$$\text{For positive effect, indicator: } X = 100 \times (A - B) \div A \tag{1}$$

$$\text{For negative effect, indicator: } X = 100 \times (B - A) \div B \tag{2}$$

As the difference between A and B increases, the value of indicator X approaches 100, which is a high score, meaning that the benefit is very pronounced. Conversely, as the difference between A and

B approaches 0, which is a low score, the value of indicator X approaches 0, meaning that there is little or no difference in the benefit between the two areas.

2 Some indicator equations must be developed on an individual basis, these are in the category of Equation 3. These indicators may be evaluated by comparison between the NBS variable (A) and expected values, literature, other case study areas, and other methods.

More details for calculating each indicator's value are listed in Supplementary Materials. Equations may be altered to suit the specific benefits of NBS. The data collected for each indicator is used as input for its corresponding equation; the output is a value for each indicator that quantifies how the benefit is causing an impact on the area with the NBS. Table 1 shows the types of equations that may be used to calculate the values of indicators.

Table 1. Indicators and equations types used for each.

Type of Equation	Related Indicators	
Equation (1): positive effects	Connectivity GWR Biodiversity Habitat provision Carbon storage Cultural and spiritual	Community interaction and development Aesthetics/property value Agriculture Economic Green jobs
Equation (2): negative effects	Historical flood mitigation Coastal flood mitigation Resilience to drought Resilience to flood Irrigation costs	Air quality Water quality Climate control Landslide risk reduction Noise quality
Equation (3): comparison of indicator values with the literature or case studies	Research Infiltration Recreational	Education Quality of life Social safety

2.1.4. Step 4: Calculation of NBS Grade

Next, each indicator value from step 3 is converted to a score using Table 2. Indicator values show the percentage difference. For example, a value of 75 with a corresponding score of 4 implies that the performance of the benefit in Area A is 75% more pronounced than in Area B. Scores less than 2 indicate that there is little or no difference between the benefit in Area A and Area B. Furthermore, they may imply that the data was not collected or analysed correctly or that the benefit is not relevant to the case study. A negative value indicates that the benefit in Area A may be inferior to Area B. When the indicator score is less than 2, the relevance, data collection, and analysis method should be re-evaluated before including it in the grade calculation.

Table 2. Indicator values and scores.

Indicator Value	Score
<20	1
20–40	2
40–60	3
60–80	4
>80	5

The grade for the NBS is determined by taking the average of all the indicator scores. An optional step may be to assign weights to the indicator scores if the stakeholders find some to be more important than the others. Weighted criteria should be defined by stakeholders depending on the level of importance for each indicator's benefit to the community. After all the scores have been weighted, they will be averaged, added, and will result in a single number; this is the NBS grade that incorporates all the benefits assessed.

The NBS grade, specific to the case study, will be the outcome of the assessment and the grades range from 1, indicating no benefits of NBS, to 5, indicating numerous benefits (for details of grades refer to Table 3) [19].

Table 3. Nature-based solutions (NBS) grades.

NBS Grade	Description	Grade Number
Very poor	The NBS do not provide any benefits; re-evaluation is necessary.	0–1
Poor	The NBS are providing very few benefits; improvements may be required; re-evaluation may be necessary.	1–2
Good	The NBS are providing some added benefits; some improvements may be required.	2–3
Very good	The NBS are providing added benefits; minor improvements may be required.	3–4
Excellent	The NBS are adding at least 80% more benefits; continue with regular maintenance.	4–5

2.1.5. Step 5: Recommendations

The final step in the framework is to make recommendations for all indicators, or only those with low scores. Recommendations can include guidance on how to better involve stakeholders in every step of the framework, how to better measure, collect, and analyse data, and how to maintain the NBS to maximize benefits. Furthermore, this step may provide advice on how to monitor the benefits of NBS to ensure they remain positive into the future, as well as how to plan for better balance between biodiversity, habitat and agricultural output, how to reduce expenses through efficient irrigation, solar powered pumping, alternate fuel and fertilizer sources, and upscaling of the particular NBS site.

3. Framework Application: Rangsit, Thailand

3.1. Case Study Areas

The case study areas used in the present work are located in the Rangsit area, in the eastern part of the Chao Phraya valley in central Thailand. Rangsit is located between the Western Raphiphat and the Rangsit canals. The case study includes two areas—Area A in Pathum Thani province (Bueng Cham O (BCO) and Noppharat (NP) sub-districts), and Area B in Saraburi province (Nong Rong (NR) sub-district), shown in the upper right-hand corner of Figure 2. The type of NBS addressed in the case study work are furrows which are located in Area A only.

Furrows represent a unique rural NBS that exist in the Rangsit area of Thailand. These are small canals in agriculture fields connected to the sub-canals through locks with gates; they are similar to the RFR concept used for high-water channel. Furrows were first built to store water for irrigation purposes, but they can also provide several other benefits including flood protection by controlling and channelling flows. Figure 3 shows typical furrows in the Rangsit area.

Most of the farmland in BCO and NP sub-districts (Area A, Figure 2) were converted from rice paddies to orange orchards in 1984, but in 1991 a citrus disease destroyed most of the trees. The Ministry of Agriculture approached farmers to consider growing palm oil trees, which were only grown in southern Thailand at the time. As a result of that, many farmers turned to palm oil production, which became profitable. However, the farmers were faced with water shortages, poorly maintained shallow canals, and flooding. The 2011 floods caused extensive bank erosion and other damages. Hence, the farmers decided to expand and deepen the network of furrows on their land. The use of furrows for water storage boosted palm production as well as many other crops, such as bananas and vegetables during dry seasons.

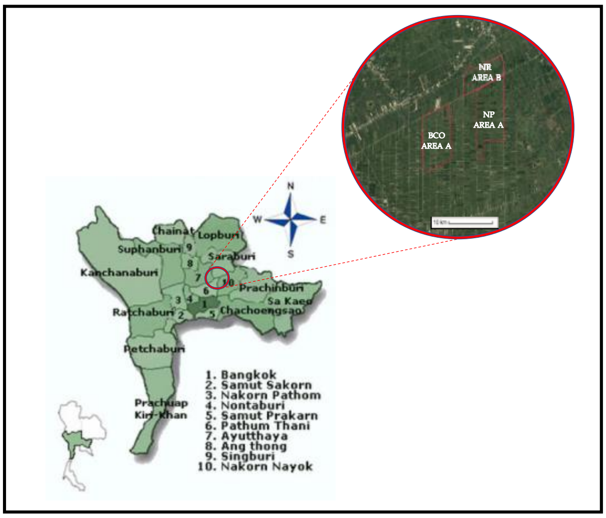

Figure 2. Central Thailand provinces and study area locations [21].

Figure 3. A typical Rangsit furrow [22].

Due to water availability throughout the year, Rangsit farmers harvested almost double of the palm oil yield from southern Thai farmers. Approximately 13,000 palm oil trees were planted along 72.8 km of canal banks to prevent erosion and also to stop illegal construction. Palm oil production resulted in higher yields than the farms in southern Thailand which did not have furrows [23].

Although it is not necessary to irrigate palm oil trees, a study in Thailand found that during the dry season, by providing up to 450 L/tree/day there will be an increase in fruit yield of up to 50% [23].

Figure 4 shows the average October rainfall from 1991 to 2016 in Thailand; two of the worst, most recent floods occurred in 2011 and 2016 (198.4 mm and 195.9 mm respectively), shown in red were used to assess the values of W1, W2, and W3 [24]. Dry season in Rangsit usually occurs from 1 November to 30 April and the monsoon season is from 1 May to 31 October each year.

It is estimated that the Rangsit area can store up to 137 million cubic meters of water (including canals, sub-canals, and furrows), which is sufficient to supply farmers throughout the year [25]. Furrows are approximately 2 m in depth, 2.5 m wide, and the network of 129 km provides 4600 m^3/ha of water storage. There were four Area A farms included in the analysis: A-1, A-2, A-3, and A-4. All farms were used for water quality measurements, and A-3 and A-4 farmers were interviewed; A-1 and A-2 farmers were not available for interviews. The average size of farms in Area A and Area B is 18 Rai (2.88 ha); approximately 20%–25% of the land surface in Area A farms is occupied by furrows.

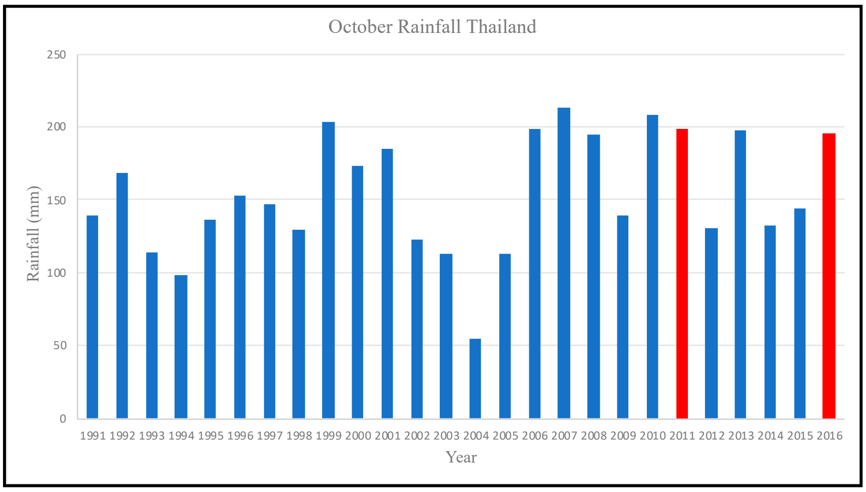

Figure 4. The 2011 and 2016 Thai floods (shown in red) [24].

In the neighbouring sub-district of NR (Area B), the farmers did not convert their rice paddies to furrows. They were reluctant to change from rice to other crops due to the high initial investment costs involved in creating furrows. Presently, the most common crop in NR is still rice. There were four Area B farms used in the analysis: B-1, B-2, B-3, and B-4. Farmers in all four farms were interviewed.

3.2. Framework Application to Rangsit Case Study Areas

3.2.1. Involvement of Stakeholders

Ten stakeholders were involved in the development and testing of the framework. Six farmers were interviewed to collect information about expenses, incomes, irrigation use, floods, droughts, crops, key indicators, and fertilizer use. A Thai translator was present during all the interviews; the questions were written ahead of time to ensure the correct information was gathered (farmer interview questions and responses are available in Supplementary Materials).

Two local municipality personnel were separately interviewed to gather knowledge about water use, crop, flood, drought, recreation, education, key indicators, area history, and culture information. Two government experts provided information concerning total area irrigation volume, groundwater usage, and groundwater well level data for the case study areas.

Time and budget resources were limited in the application and testing of the framework. For future application of the framework, it is recommended that larger sample sizes are used, and that focus group discussions with stakeholders are included.

3.2.2. Step 1: Selection of Benefit Categories

Rangsit stakeholders were interested in all three benefit categories (water, nature, and people) and they wanted to see how the benefits of flooding and drought resilience, water storage, GWR, biodiversity of crops, water quality, farmer incomes, and farm productivity were performing in their respective communities.

3.2.3. Step 2: Selection of Indicators

Through discussions with stakeholders on what indicators were applicable to the case study areas and important to the community, the list in Table 4 was produced. The selection process involved choosing relevant indicators and eliminating those that were irrelevant. For each selected indicator, the reason for selection and data source are shown in Table 4.

Table 4. Rangsit indicator selection.

Indicator	Reasons for Selection	Data Source
W1: Local flood mitigation W2: Downstream flood mitigation	Occurrence of past flood event (2016). Hydrodynamic model for Rangsit was available.	World Bank database (rainfall)
W3: Historical flood mitigation	Occurrence of past flood event (2011).	2011 Flood map
W4: Water storage and reuse	Dimensions of the furrows, storage capacity, and furrow water use information were available.	Previous research [22] Farmer interviews
W5: Irrigation cost	Irrigation costs were available.	Farmer and government expert (irrigation department) interviews
W6: Resiliency to drought	Incomes in drought and non-drought years were available.	Farmer interviews
W7: Connectivity	Aerial images were available.	Google Earth
W8: GWR	Rainfall data and groundwater monitoring well level data were available. Declining groundwater level was a concern in Thailand.	World Bank database (rainfall) Government expert interview (groundwater resources)
W9: Water quality	Water sampling locations, and TSS and turbidity measuring equipment were available.	In-situ sampling
N1: Infiltration	Test locations and infiltration rings were available.	In-situ sampling
N2: Biodiversity	Species information was available.	Farmer and municipality interviews
N3: Soil quality	Soil sampling locations and a testing laboratory were available.	In-situ sampling
N4: Fertilizer reduction N5: Air quality	Fertilizer use and carbon emission information were available.	Farmer interviews
P1: Cultural and spiritual P2: Education and research	Number of events were available.	Farmer and municipality interviews
P3: Economic P4: Agricultural	Annual incomes and expenses information were available.	Farmer interviews

3.2.4. Step 3: Calculation of Indicator Values

The following section describes how the data was collected and analysed and how the equations given in Supplementary Materials were applied.

(1) Water related indicators

The nine water related indicators in Table 4 were analysed for the Rangsit case study areas and the details are provided below.

MIKE HYDRO River one-dimensional hydrodynamic modelling software, developed by the Danish Hydraulic Institute (DHI), was used for flood analysis in the Area A canals using October 2016 flood data. It used unsteady, nonuniform flow to simulate flows from different sub-catchment areas; which resulted in changes in water levels and discharges at five cross-sections along Klong 10 and five along Klong 1 (Klong is the Thai word for canal). The NBS storage was represented as artificial storage within the network and a weir with storage was introduced to represent the furrows.

The model used upstream and downstream flow regulators and downstream Q/h relationships for the boundary conditions; see Figure S3 in Supplementary Materials [22].

Figure 5 shows the MIKE HYDRO River model network of the Rangsit area. Area A (marked with orange colour) is located in the upper right-hand corner. October 2016 flood data was first simulated in the case study area without storage and then again with the NBS storage; refer to Figure 5 for the storage location on Klong 10 (K10). The model was used to determine values for indicators W1 and W2; W1 measured Area A flooding at K10 cross-sections and W2 measured downstream flooding at Klong one cross-section.

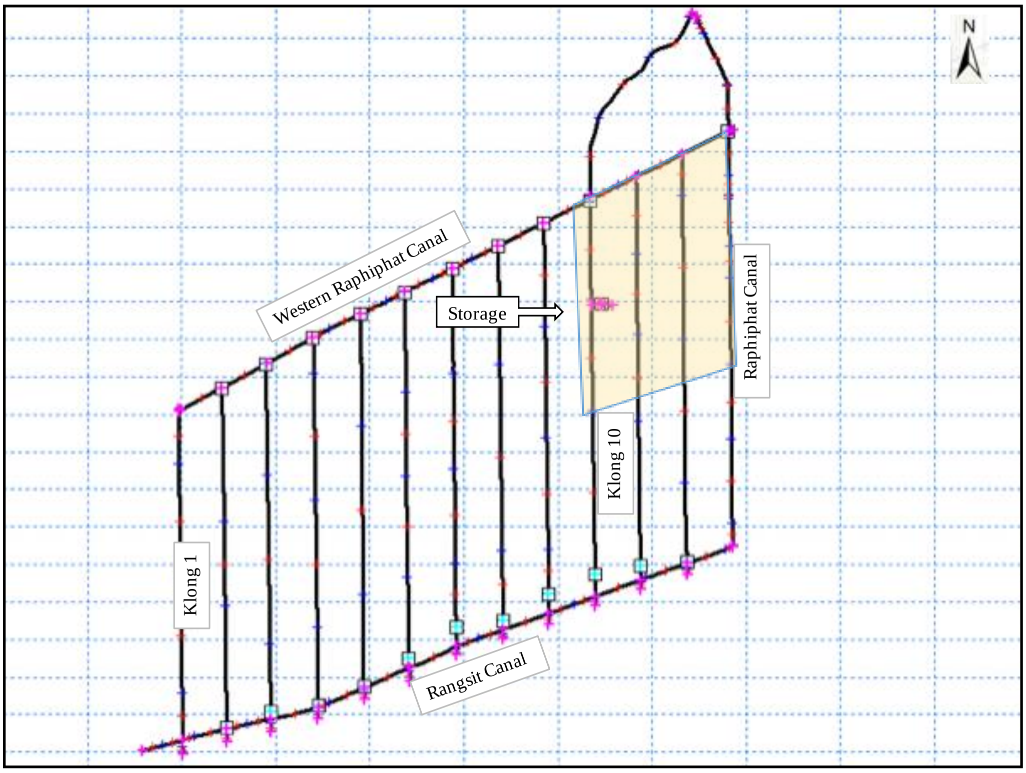

Figure 5. MIKE HYDRO River model network showing NBS storage location (Area A is indicated in orange).

W1: Local flood mitigation

The furrow storage was estimated at one million cubic meters; flood water levels (heights above the canal bank elevations) were recorded at five cross sections upstream and downstream of the storage location at K10 with and without the storage (see Table 5 for water height levels). Figure 6 depicts a typical cross section of the canal (black line) where high and low water levels (red and green dashed lines), current water level (solid blue), and canal dimensions (faint red dashed lines) are shown for the October 2016 flood event; the left bank shows flooding in this particular cross-section.

To understand the significance of the furrow storage, the flood level reduction was compared to the water level at which maximum damage occurs in typical Asian agriculture (obtained from a depth-damage curve). Figure S1 in Supplementary Materials shows the agricultural depth–damage graph for Asia [26].

As shown in Figure S1, the maximum damage occurred in agriculture at 4.8 m of flood water; mid-range damage occurred at 1.4 m; the steepest slope, or highest rate of damage occurred between 0.5 and 1.0 m of flood water. Agricultural damage is the lost output when crops are destroyed by flooding. The maximum average agricultural damage in Asia was 0.022 USD/m^2 of land (2010 prices) [26]. Using a flood depth of 0.5 m (above which most damage occurs), the ability of the furrows to reduce this value was assessed. This indicator provided an estimate of how furrows affected local flooding in the rural area around K10 in Area A. Using Equation (3) the result for W1 was 43.

Table 5. Water depths in K10 canal with and without furrow storage.

Cross-Section	A. Top Canal Bank (m)	B. Max Water Level (No Storage) (m)	C. Height Difference (m) A–B	D. Max Water Level (with Storage) (m)	E. Height Difference (m) A–D	Flood Height Reduction (m) C–E
K10-1	3.828	5.246	−1.418 *	5.031	−1.203 *	−0.215
K10-2	3.593	5.246	−1.653 *	5.03	−1.437 *	−0.216
K10-3	3.6	5.246	−1.646 *	5.03	−1.43 *	−0.216
K10-4	3.767	5.246	−1.479 *	5.03	−1.263 *	−0.216
K10-5	3.136	5.246	−2.11 *	5.03	−1.894 *	−0.216
	Average flood height reduction due to the addition of storage:					−0.216

D (height of maximum damage from depth-damage curve) = 0.5 m
H_{st} (flood height reduction with NBS storage) = 0.216 m

W1 = 100 [1 − (D − H_{st}) ÷ D] = 100 [1 − (0.5 − 0.216) ÷ 0.5] = 43

Remark * Negative values in columns C and E indicate flooding.

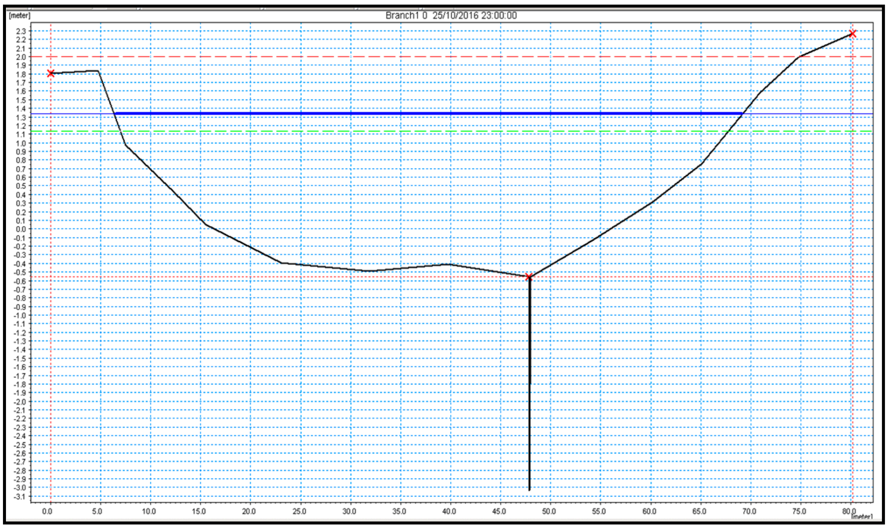

Figure 6. MIKE HYDRO River model cross-section on K10.

W2: Downstream flood mitigation

Indicator W2 measured the potential flood mitigation potential of the furrow storage in Area A at a downstream commercial location, Klong 1 (K1).

The same model and method were used for indicators W1 and W2; for W2 the flood water levels were recorded at five cross-sections along K1; indicated in Figure 5; simulation data and the equation are shown in Table 6.

Table 6. Water depths in K1 with and without furrow storage.

Cross-Section	A. Top Canal Bank (m)	B. Max Water Level (No Storage) (m)	C. Height Difference (m) A–B	D. Max Water Level (with Storage) (m)	E. Height Difference (m) A–D	Flood Height Reduction (m) C–E
K1-1	3.684	3.392	0.292	3.392	0.292	0
K1-2	3.684	3.286	0.398	3.286	0.398	0
K1-3	2.319	3.004	−0.685 *	3.004	−0.685 *	0
K1-4	2.834	1.971	0.863	1.971	0.863	0
K1-5	1.836	1.499	0.337	1.499	0.337	0
	Average flood height reduction due to the addition of storage:					0

D (height of maximum damage from depth-damage curve) = 0.5 m
H_{st} (flood height reduction with NBS storage) = 0 m
W2 = 100 [1 − (D − H_{st}) ÷ D] = 100 [1 − (0.5 − 0) ÷ 0.5] = 0

Remark * Negative values in columns C and E indicate flooding.

To understand the significance of the furrow storage, the flood level reduction was also compared to the height at which maximum damage occurred in commercial areas in Asia; Figure S2 in Supplementary Materials shows the Commercial depth–damage graph for Asia [26]. Using Equation (3) the result for W2 was 0.

W3: Historical flood mitigation

This indicator compared flooded areas in Area A and Area B for the 2011 flood event. Figure 7 shows a 2011 flood map that was used to estimate the areas of flooding. Purple indicates flooding and light blue indicates dry land; Area A and Area B are shown in the northeast corner. Since the 2011 flood map shows only a portion of Area B, the same sized area in Area A was used for comparison. Approximately 35.6% of Area A and 63.8% of Area B were flooded during the 2011 flood event. The resulting value for W3, using Equation (2), was 44.

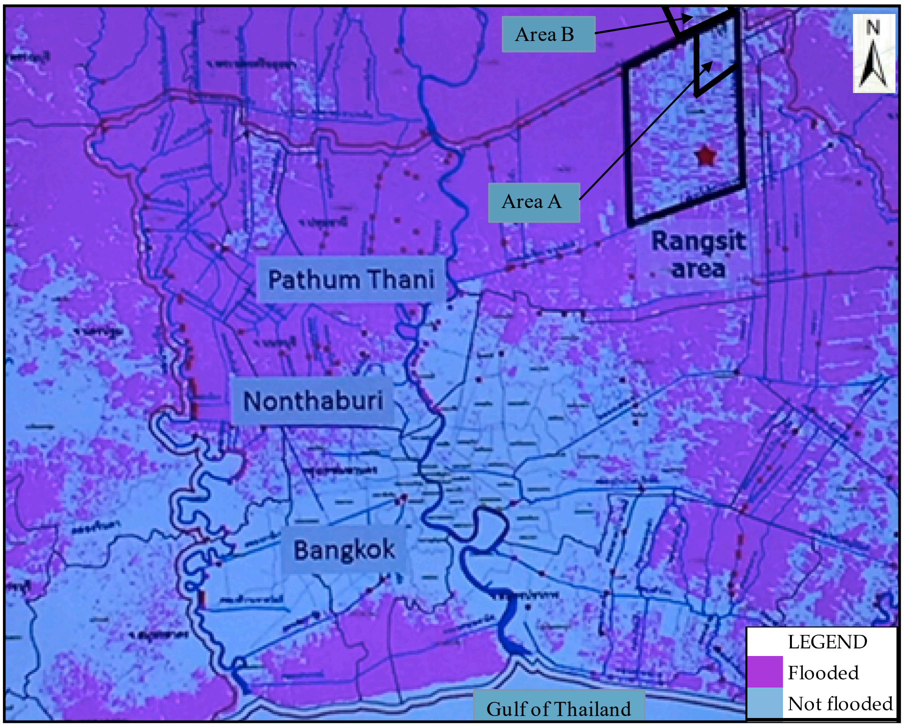

Figure 7. Case study areas; 2011 flood map [25].

W4: Water storage and reuse

The water storage and reuse potential of the furrows in Area A were evaluated based on the percentage of time that the farmers had adequate irrigation water. Information was gathered during interviews with farmers in the NP sub-district (see Figure 2). Area B was not used for comparison since there were no furrow water storage and reuse potentials in this sub-district. Farmers in Area A were able to use furrow water for irrigation 85% of the year; the resulting value for W4, using Equation (3) was 85.

W5: Irrigation cost

The cost (Baht/year/Rai) for all sources of irrigation (furrows, canals, and groundwater) was compared in Area A and Area B. During interviews, the farmers provided the total yearly irrigation cost for their farm; this included electricity, equipment, fuel, labour, and all operation costs; refer to Table 7 for details of irrigation costs (2016). Groundwater use was rare. Using Equation (2) the result for W5 was −75.

Table 7. Irrigation costs.

Farm	Irrigation Cost and Units	Farm Size (Rai)	Irrigation Cost (Baht/year/Rai)
A-3	350 Baht/week	18	1011
A-4	1750 Baht/month	18	1167
	Average Area A farms (A):		1089
B-1	12,000 Baht/year	36	333
B-2	12,000 Baht/year	9	1333
B-3	24,000 Baht/year	36	670
B-4	1250 Baht/year	8.3	150
	Average Area B farms (B):		622
W5 = 100 [(B − A) ÷ B] = 100 [(622 − 1089) ÷ 622] = −75			

W6: Resilience to drought

This indicator compared lost farm income between a non-drought year (2016) and drought year (2015). During interviews, farmers provided their annual incomes for 2015 and 2016. Thailand experienced a drought in 2015, when dam levels dropped below 10%, and 30% of the country was on water restrictions. The rainy season, usually beginning in May did not start until August; refer to Table 8 for details of farm incomes. Using Equation (2) the result for W6 was −150.

Table 8. Loss of farm income (2015 to 2016).

Farm	Loss of Income (%)
A-3	0
A-4	30
Average Area A farms (A): 15	
B-1	50
B-2	20
B-3	20
B-4	−67 (gain)
Average Area B farms (B): 6	
W6 = 100 [(B − A) ÷ B] = 100 [(6 − 15) ÷ 6] = −150	

W7: Connectivity

The lengths of water channels (canals and furrows) in Area A and Area B were compared and lengths were estimated using Google Earth; refer to Table 9 for details. This indicator showed how furrows may have contributed to the distribution of sediment, organisms, and nutrients in the water systems. The higher the water connectivity was, the easier it would have been for these elements to move in the environment [27]. Using Equation (1) the result for W7 was 72.

Table 9. Total length of canals and furrows in case study areas.

Area	(1) Length of Canals (km)	(2) Length of Furrows (km)	(3) Area of Sub-District (km^2)	Total Length Per Area (km/km^2) [(1) + (2)] ÷ (3)
A	51.12	254.80	66.1	4.63 (A)
B	34.3	0	26.7	1.28 (B)
W7 = 100 [(A − B) ÷ A] = 100 [(4.63 − 1.28) ÷ 4.63] = 72				

W8: GWR

According to the literature, Area A had an estimated rate of GWR of between 5% [28] and 14% [29] of annual rainfall. The average annual rainfall (2001 to 2017) for the Thai province of Pathum Thani was 1497.8 mm/year; therefore, the anticipated GWR was between 75 mm/year (5%) and 210 mm/year (14%).

Both the Water Table Fluctuation (WTF) method and groundwater monitoring well records could not be used to estimate GWR due to the presence of confined aquifers below the case study area; water that infiltrated did not necessarily recharge aquifers directly below.

However, infiltration will be higher in the areas with furrows; infiltration is directly related to GWR, even if the GWR is occurring in other sub-districts. This indicator compared the surface area of water in Area A and Area B. The areas were estimated using Google Earth; the area was 22.2% for Area A and 4.7% for Area B. The resulting value for W8, using Equation (1), was 79.

W9: Water quality

Primary treatment of water removes the larger solid particles such as grit, sediment, and floating debris [30]. Water that entered the NBS carried sediment and pollutants from other water bodies or from runoff. Without this process, the pollutants would have remained in the sub-canals and canals; therefore, the water quality in the canals was improved.

If the Area A furrows provided some primary water treatment for the main canal, the sediment in the furrows would have been higher than in the canals. Sediment was represented by measuring levels of total dissolved solids (TDS) and turbidity; total suspended solids (TSS) may also be used, but this test was unavailable. Furrow water samples from Area A farms (A) were tested onsite with a portable TDS probe and a portable turbidity meter, as well as Klong 12 (K) where the water originated; refer to Table 10 for test results. Using Equation (3) the result for W9 was 45.

Table 10. TDS and turbidity for Area A furrows and Klong 12.

Parameter	Furrows A-1 to A-4 (A)	K12 Canal (K)	$[(W_{i,K} - W_{i,A}) \div W_{i,K}]$
Average TDS (ppm)	453	291	0.36
Average turbidity (NTU)	86	39	0.55
W9 = average $[(W_{i,K} - W_{i,A}) \div W_{i,K}]$ 100 = average (0.36, 0.55) 100 = 45			

Remark: The symbol i represents the different parameters; in this case there are two: TDS and turbidity.

(2) Nature related indicators

The five nature related indicators in Table 4 were analysed for the Rangsit case study areas; the details are provided below.

N1: Infiltration

Infiltration is an indication of healthy soil. A soil that is porous, drains well, and helps prevent runoff and erosion is considered healthy [31]. The locations in Area A with furrows would have experienced infiltration. How the furrows contributed to infiltration was of interest; since there are no furrows in Area B, they were not used for comparison. Instead, infiltration rates, measured beside the furrows were compared to the literature rates for the same soil type. Infiltration rates were measured at farms A-3 and A-4 using double stainless-steel infiltration rings (30 cm inner ring and 60 cm outer ring).

In-situ measurements of infiltration measured in the field (A) were compared to infiltration calculated using the Green Ampt method and through the literature infiltration rates (L); refer to Table 11 for infiltration rates and Table S7 in Supplementary Materials for parameters [32]. Using Equation (3) the result for N1 was 69.

Table 11. Infiltration rates for Area A.

Infiltration Method		Infiltration Rate (mm/hour)
Using site parameters (A)	Infiltration rings	7.5 (average of 6, 9)
	Green Ampt	10.2 (see Table S7)
	Literature	10.0 [33]
	Average A:	9.2
Desired infiltration (L)	Literature	13.3 [34]
N1 = 100 [1 − {(L − A) ÷ L}] = 100 [1 − {(13.3 − 9.2) ÷ 13.3}] = 69		

N2: Biodiversity

Biodiversity, in terms of variety of plant and animal species, in Area A and Area B was compared by determining the number of different crops; this information was collected during interviews with farmers and municipal staff. High biodiversity is an indication of a healthy environment [35]. Area A had 20 species and Area B had 5. The resulting value for N2, using Equation (1), was 75.

N3: Soil quality

This indicator was added at the request of stakeholders; it was specific to Area A. Farmers dredged sediment from the furrows once or twice per year and applied it to their land. Many farmers felt that the sediment was rich in nutrients, since it originated from the canals that contained agricultural runoff. This indicator compared the nutrients (nitrogen (N), phosphorus (P), and potassium(K)) of the furrow sediment (S) to nutrients in the native soil (N) at farms in Area A; samples were collected from two farms in Area A and analysed at Central Laboratory Co. in Bangkok; refer to Table 12 for test results. Central Laboratory used an in-house method TE-CH-211 based on AOAC (2012) 993.13 for total nitrogen analysis, in-house method TE-CH-183 based on AOAC (2012) 958.01 for total phosphorus, and manual on fertilizer analysis, APSRDO.DOA; 4/2551 for total potassium analysis. Using Equation (3) the result for N3 was 17.

Table 12. Sediment and soil sample testing results.

Farm	Sample Type	Total Nitrogen (%)	Total Phosphorus (%)	Total Potassium (%)
A-3	Sediment (S)	0.5	0.5	0.25
	Soil (N)	not detected	0.6	0.22
A-4	Sediment (S)	0.5	0.5	0.19
	Soil (N)	0.5	0.5	0.22
Average sediment (S):		0.5	0.5	0.22
Average soil (N):		0.25	0.5	0.22
$[(Z_{i,S} - Z_{i,N}) \div Z_{i,S}]$:		50	0	0
N3 = average $[(Z_{i,S} - Z_{i,N}) \div Z_{i,S}]$: average (50,0,0) = 17				

N4: Fertilizer reduction

Soil quality can also be estimated based on the quantity of fertilizer that was applied; the less fertilizer required, the better the quality of the soil. This indicator was added at the request of stakeholders, and was specific to Area A. Many farmers believed that by spreading sediment from the furrows onto the land, they required less fertilizer. This indicator compared the mass of fertilizer used in Area A to Area B in 2016, and information was collected from farmers during interviews; refer to Table 13 for fertilizer usage details. Using Equation (2) the result for N4 was 5.

Table 13. Farm fertilizer use.

Farm	Farm Area (Rai)	Baht/Year	Kg Fertilizer/Year	Kg Fertilizer/Year/Rai
A-3	18	5000	250	14
A-4	18	30,000	1500	83
Average Area A farms (A): 49				
B-1	36	28,800	1440	40
B-2	9	13,400	670	74
B-3	36	32,000	1600	44
B-4	8.3	7470	374	45
Average Area B farms (B): 51				
N4 = 100 (B − A) ÷ B = 100 (51 − 49) ÷ 52 = 5				

N5: Air quality

Lal (2004) conducted a review of research on the conversion of energy used by farm operations into its carbon equivalent (CE). It was estimated that for every kilogram of fertilizer used, 1.70 kg of CE were produced [36]. Since the difference in fertilizer use in Area A and Area B was insignificant (see N4) this method was not used.

Air pollution may also be quantified by measuring emissions such as carbon and nitrogen dioxide in the air. This indicator evaluated air quality using a remote sensing database for nitrogen dioxide levels between 10 July 2018 and 28 January 2019 [37]. Figure 8 shows the differences in emissions in Area A and Area B; the NO_2 concentrations were 0.054 mmole/m^2 for Area A and 0.059 mmole/m^2 for Area B. The resulting value for N5, using Equation (2), was 8.5.

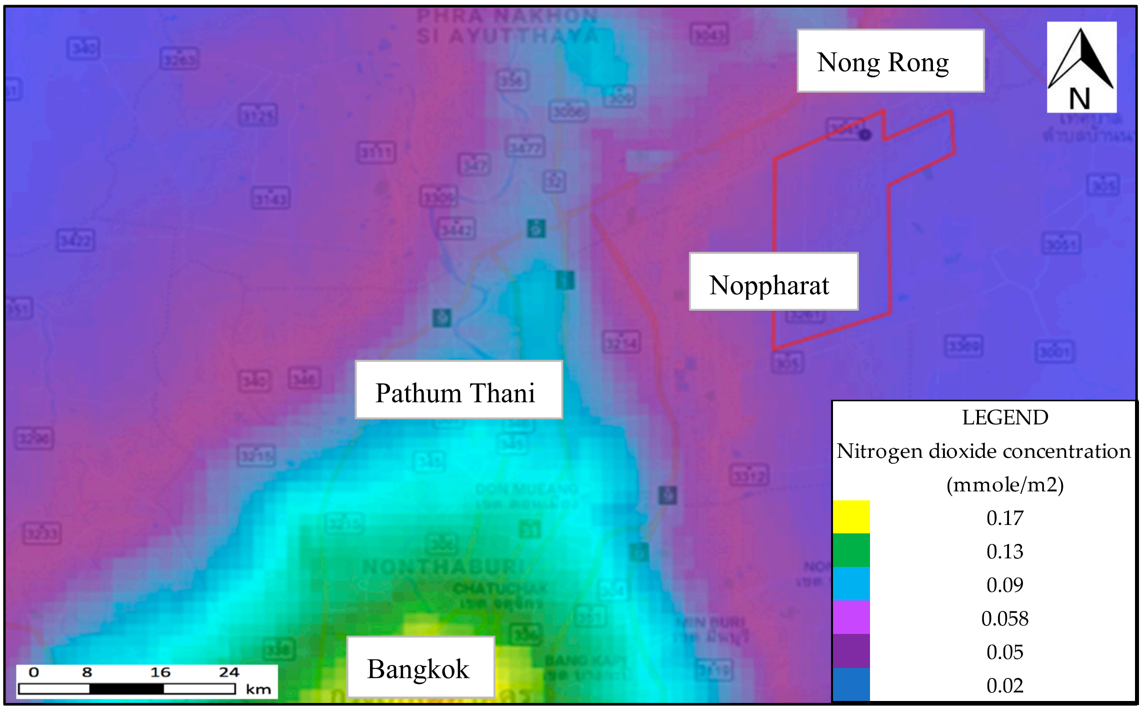

Figure 8. Remote sensing NO_2 map of central Thailand [37].

(3) People related indicators

The four people related indicators in Table 4 were analysed for the Rangsit case study areas; the details are provided below.

P1: Cultural and spiritual

This indicator compared the number of cultural and spiritual events in Area A and Area B in the same year. During interviews, farmers and municipal staff were unable to identify any cultural or spiritual events that took place in Area A or Area B in 2017, as a result, the value for P1, using Equation (1) is 0.

P2: Education and research

In Malmo, Sweden the Western Harbour has become an international model of green infrastructure; it brings more than 800 people every year to study the benefits and performance of the project [38]. This case study is similar to Rangsit in that they are both innovative examples of NBS projects that attract recognition and offer valuable research opportunities. The Malmo example was used as a baseline value for indicator P2; NBS with 800 people attending events was assigned a high value of 80:800 ÷ 10.

The number of people that attended education and research events in Area A were identified through interviews with municipal staff. Over 900 people visited Area A in 2016 to study the furrows (students, communities, and government officials); the resulting value for P2, using Equation (3) was 90. This indicator was specific to NBS; therefore, Area B was not included.

P3: Economic

The incomes (Baht/year/Rai) of farmers in Area A and Area B were compared for this indicator. During interviews, farmers from farms A-3, A-4, and B-1 to B-4 provided annual farm incomes for 2016; refer to Table 14 for details. Using Equation (1) the result for P3 was 77.

Table 14. Farm incomes for Farms A-3, A-4, and B-1 to B-4 (2016).

Farm	Income (Baht/Year/km^2)
A-3	27,778
A-4	22,222
Average Area A farms (A): 25,000	
B-1	4089
B-2	12,222
B-3	6667
B-4	361
Average Area B farms (B): 5835	
P3 = 100 (A − B) ÷ A = 100 (25,000 − 5835) ÷ 25,000 = 77	

P4: Agriculture

This indicator compared the productivity in Area A to Area B. The productivity was calculated as agriculture outputs divided by inputs ($/$); the higher the productivity, the more profitable the farm was. Farm output and input for 2016 were collected during interviews with farmers. Agriculture outputs included profits made through the sale of crops (Baht/year); agriculture inputs included costs of seeds, pesticides, fertilizers, packaging, tools, equipment, gas and oil, and labour (Baht/year); investment costs were not included; refer to Table 15 for productivity details. Using Equation (1) the result for P4 was 70.

Table 15. Farm productivity (2016).

Location	Income (Baht/Year/km^2)	Expenses (Baht/Year/km^2)	Productivity (Income/Expenses)
A-3	27,778	1667	
A-4	22,222	5556	25,000/3611 = 6.9
Average A:	25,000	3611	
B-1	4089	4000	
B-2	12,222	4444	
B-3	6667	2778	5835/2848 = 2.0
B-4	361	169	
Average B:	5835	2848	
P4 = 100 (A − B) ÷ A = 100 (6.9 − 2.0) ÷ 6.9 = 70			

3.2.5. Step 4: Calculation of NBS Grade

Weights were applied to the indicator scores. Stakeholders ranked the benefits in order of importance using four categories: safety, income, environmental improvement and pastime; weights were assigned accordingly as shown in Table 16.

Table 16. Weight criteria for Rangsit indicators.

Category	Indicators	Weight
Safety	Local flood mitigation Downstream flood mitigation Historical flood mitigation	0.45
Income	Economic Agricultural Irrigation cost Resiliency to flood	0.30
Environmental improvement	Water storage and reuse Connectivity Infiltration GWR Biodiversity Soil quality Fertilizer reduction Air quality Water quality	0.15
Pastime	Cultural/spiritual Education and research	0.10

Remark: Weights must add to 1.0.

The next step converted the indicator values into scores using Table 2. If the score for any indicator was less than two, that indicator may not have been relevant to the NBS or a different method of assessment may have been required. Indicators that required further assessment are shown in brackets in Table 17. Weights were applied to the average score in each weight category by multiplying the average score by the weight (see the last column in Table 17), the sum of the weighted average scores became the furrow grade; refer to Table 17 for grade calculation details.

Table 17. Furrow grade calculation.

Indicator	Name	Calculated Value	Score (Using Table 2)	Average Score	Weight	Weighted Average Score (Average Score × Weight)
W1	Local flood mitigation	43	3	3	0.45	1.35
W2	{Downstream flood mitigation}	{0}	{0}			
W3	Historical flood mitigation	44	3			
P3	Economic	77	4	4	0.3	1.2
P4	Agricultural	70	4			
W5	{Irrigation cost}	{−75}	{1}			
W6	{Resiliency to flood}	{−150}	{1}			
W4	Water storage and reuse	85	5	4	0.15	0.6
W7	Connectivity	72	4			
N1	Infiltration	69	4			
W8	GWR	79	4			
N2	Biodiversity	75	4			
N3	{Soil quality}	{17}	{1}			
N4	{Fertilizer reduction}	{4}	{1}			
N5	{Air quality}	{1}	{1}			
W9	Water quality	45	3			
P1	{Cultural/spiritual}	{0}	{0}			0.5
P2	Education and research	90	5	5	0.1	
Furrow grade (sum of weighted scores):						**3.65**

Remark: Terms within brackets were not used in the furrow grade calculation.

The furrow grade was 3.65, referring to Table 3, this grade corresponds to very good: the furrows are providing added benefits; minor improvements may be required. The next step involved making recommendations for improving the performance of each indicator.

3.2.6. Step 5: Recommendations

The final step in the framework was to provide recommendations on how to improve or better quantify the benefits of the furrows; this information may be helpful in project management, budget, maintenance, and labour resource planning for decision makers. Recommendations for each indicator are shown in Table 18 for the case study area; decision makers may choose to follow all, or only those that are important to the community and within their budget.

Table 18. Recommendations for Rangsit indicators.

Indicator	Recommendations
W1 Flood mitigation: local, rural	Flood preparedness • improve communication between flood forecasting and local communities • improve emergency plan Educate other agricultural communities and governments on furrows Implement furrows in other areas
W2 Flood mitigation: downstream, urban	Increase water storage capacity • add more furrows or NBS • maintain canals regularly to minimize sediment build-up
W3 Flood mitigation: historical	Improve flood water storage capacity • extend or deepen furrow network • dredge sediment from canals and furrows regularly • keep gates well maintained
W4 Water storage and reuse	Increase the storage capacity • increase furrow networks • widen or deepen furrows • maintain furrows regularly to prevent sediment build-up • fill furrows more before the dry season Plant drought-resistant crops during dry season Use more efficient irrigation methods

Table 18. *Cont.*

Indicator	Recommendations
W5 Irrigation cost	Reduce irrigation costs • plant more drought resistant crops • use efficient irrigation methods • consider more solar pumping systems
W6 Resiliency	Increase drought resiliency • use drought resistant crops during dry season • increase water storage • use more efficient irrigation methods
W7 Connectivity	Improve water connectivity • create more furrows • remove man-made barriers in water channels • connect and restore wetlands
W8 GWR	Improve GWR • improve infiltration (see N1) • reduce groundwater pumping
W9 Water quality	Improve water quality • increase flow of sub-canal water into furrows • increase suctioning frequency of sediment from the furrows • look at benefits of using furrow sediment in more areas • decrease upstream pollution
N1 Infiltration	Increase infiltration • employ methods of tilling/aerating soil • add more porous soils • decreasing impervious area • add organic residues like groundnut stover, tamarind or rice straw to improve soil quality [34]
N2 Biodiversity	Increase biodiversity • plant a variety of crops and trees • increase areas with water Obtain the services of a professional biologist for a more thorough analysis
N3 Soil quality: nutrients	Improve soil quality • increase suctioning frequency of furrows • reduce upstream pollution
N4 Soil quality: fertilizer use	Reduce fertilizer use • understand specific plant fertilizer requirements • improve soil quality by adding organics • avoid burning crop waste; leave it on land and till into soil
N5 Air quality	Reduce pollutants • use crop species that have high carbon sequestration capabilities • reduce fertilizer use • avoid burning crop waste • use renewable energy sources for pumping and other farm equipment operation
P1 Cultural and spiritual	Discuss the benefits of furrows with community members
P2 Education and research	Continue to promote the use of furrows to others
P3 Economic: Incomes	Improve crop yield • use crops suited to the local conditions • optimize conditions for planting, watering, fertilizing, and harvesting
P4 Agricultural productivity	Improve productivity • study cultivation and rainfall patterns to optimize crop growth • plant more drought resistant crops in dry season and crops that consume less water • reduce expenses

4. Discussion

A framework for assessing implemented NBS was developed and tested on the Rangsit case study. The work to date suggests that the framework may be used to gain better understanding of benefits and co-benefits of NBS and to promote their implementation. The five-step quantitative post-implementation assessment framework can be seen as a valuable tool that may be used by stakeholders to evaluate the performance and potential advantages of their NBS.

Many of the Rangsit indicators provided an appropriate assessment of the NBS benefits. The calculated values of the 18 case study indicators are presented in Figure 9.

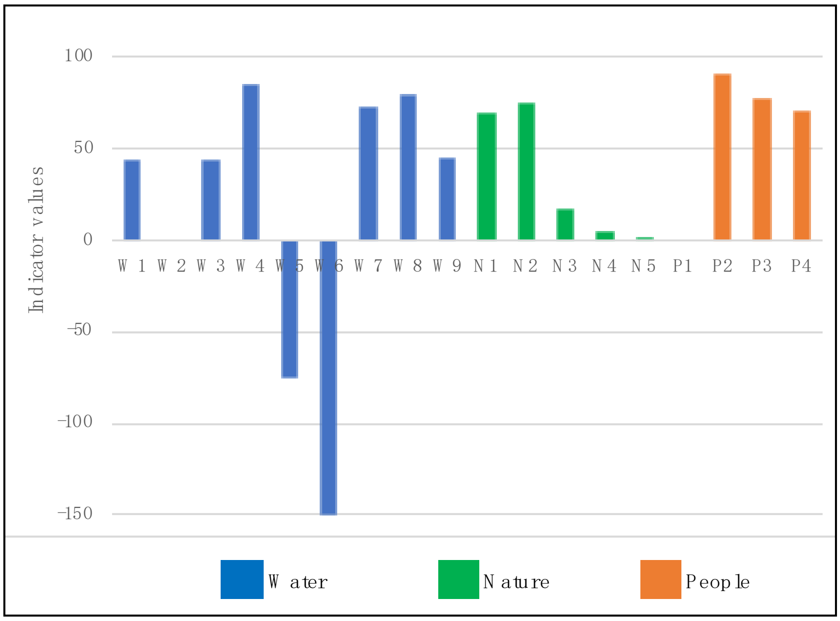

Figure 9. Values for each indicator.

The indicators with the best performance were water storage and reuse (W4) and education and research (P2). This is due to the extensive network of furrows in the area and the widespread communication with other communities about the benefits of furrows. The indicators with low performance were local flood mitigation (W1), historical flood mitigation (W3), and water quality (W9). These indicators show that if improvements are made, such as more frequent dredging of canals and furrows, their scores will likely improve.

Seven indicators with scores less than 2 were excluded from the final score, these were W2, W5, W6, N3, N4, N5, and P1. To understand downstream flood mitigation (W2) capabilities of the NBS more accurately, the total furrow storage volume of the entire district should be used and not just from Area A. To get a more accurate value for irrigation costs (W5), resiliency to drought (W6), and soil quality (N3), larger sample sizes are required. The indicators of fertilizer use (N4) and air quality (N5) are relevant to the case study but a different way to measure them is required; comparing fertilizer use in Area A to Area B, where the crops had completely different needs, was an incorrect way to assess these indicators; a better method may be to determine the carbon sequestration capabilities of the plant species. The cultural (P1) indicator was not applicable in this agricultural setting.

The final grade for the Rangsit furrows was 3.65 which is assessed to be very good. This grade indicates that the benefits due to the NBS in Area A are greater than in Area B which does not have an NBS. The sample sizes in the research were small due to limited time and budget. The Rangsit municipality contacted farmers in the areas to set up interviews; unfortunately, only two farmers in Area A and four in Area B were available for interviews. The average of the data collected from the Area A and Area B farms was used to calculate indicator values. For a more in-depth analysis of the benefits, it is recommended to increase the samples sizes, gather more data, and to hold more workshops and interviews with the stakeholders.

The outcome of the framework application demonstrates the extent of advantages of NBS, how each benefit is performing, and where improvements can be made. The framework can be repeated numerous times over a span of several years to ensure the performance of the NBS is maintained. Furthermore, a monitoring program may provide insights into how NBS and their benefits change over time.

The framework can be found valuable for:

- Researchers who want to study the impacts from NBS on climate change;
- Water managers and planners who wish to promote, upscale, and implement NBS;
- Decision makers who may want to allocate budget for NBS construction, expansion, maintenance, and monitoring;
- Farmers who may want to improve, maintain, and expand their NBS to optimize the economic benefits;
- All stakeholders who would like to understand the full benefits of NBS.

Incorporating NBS in communities may improve their resilience to climate change; NBS can diminish the effects of drought, landslides, pollution, illness, poverty, and flooding. Figure 7 depicts the impacts that furrows had on the Rangsit area during the 2011 flood event. NBS are becoming more important as the climate worsens, the knowledge of their capabilities should be spread to all stakeholders and the framework presented here offers a method to accomplish such objective.

The framework fills several gaps in the existing knowledge base related to NBS evaluations. The framework can be applied to urban and rural, large and small scale, hybrid, and catchment scale NBS, and it suggests several methods to assess both qualitative and quantitative benefits while integrating stakeholder's preferences.

5. Conclusions

There are many examples of NBS around the world that have proven their potential in providing benefits to water management, nature, and people. Hence, it is important to quantify and document the performance of their benefits so that the others can gain better understanding of their potential and significance. There are several frameworks that are proposed to date, but none of them can be used to assess the full potential of implemented NBS. The present paper proposes a framework that can be applied to any implemented NBS and it was tested on and adapted to a case study area in Thailand. The framework addresses both qualitative and quantitative benefits while integrating stakeholder's preferences.

The framework presented here evaluates how implemented NBS are performing and provides information of how they may be improved or sustained. The framework consists of five main steps: selection of NBS benefit categories, selection of NBS indicators, calculation of indicator values, calculation of NBS grade, and making recommendations for each indicator. Most importantly, the framework offers a tangible way for decision makers to understand the benefits, giving NBS more credibility, and hopefully elevating them to a mainstream infrastructure choice.

Application of the framework involved ten stakeholders who provided the necessary information for each step; it was revealed that the NBS were providing a wide variety of benefits, some were performing well, and others required improvements. The work undertaken in Thailand demonstrated that NBS such as furrows in agricultural land are beneficial for flood mitigation as well as for several other co-benefits. This information can be used by the farmers to improve their livelihoods, resilience to climate change, and their communities. The framework output also provides valuable information to support academics, water managers, and planners when studying, promoting, and implementing NBS.

The framework presented here did not include the calculation of benefits in monetary terms. By translating the indicator values into economic benefits, stakeholders are more likely to see the value and incorporate NBS in their projects. Therefore, in our future work we will attempt to further develop the framework to include a methodology for assigning monetary values to a variety of benefits and co-benefits.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/11/23/6788/s1, Figure S1: Agriculture flood depth-damage curve, Figure S2: Commerce flood depth-damage curve, Figure S3: Model domain and boundary conditions, Table S1: NBS potential water related indicators, Table S2: NBS potential nature related indicators, Table S3: NBS potential people related indicators, Table S4: Water related indicators and equations, Table S5: Nature related indicators and equations, Table S6: People related indicators and equations, Table S7: Green Ampt infiltration parameters.

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References

1. EM-DAT, The International Disaster Database, 2019. 2018: Extreme Weather Events Affected 60m People. Available online: https://www.unisdr.org/archive/63267 (accessed on 18 September 2019).
2. Alves, A.; Gersonius, B.; Sanchez, A.; Vojinovic, Z.; Kapelan, Z. Multi-criteria approach for selection of green and grey infrastructure to reduce flood risk and increase CO-benefits. *Water Resour. Manag.* **2018**, *32*, 2505–2522. Available online: https://www.springerprofessional.de/en/multi-criteria-approach-for-selection-of-green-and-grey-infrastr/15540230 (accessed on 9 August 2019). [CrossRef]
3. Dige, G.; Eichler, L.; Vermeulen, J.; Ferreira, A.; Rademaekers, K.; Adriaenssens, V.; Kolaszewska, D. *Green Infrastructure and Flood Management*; EEA Report; European Environment Agency: Luxembourg, 2017; Volume 14, pp. 1–156, ISBN 978-92-9213-894-3. Available online: https://www.eea.europa.eu/publications/green-infrastructure-and-flood-management (accessed on 9 November 2018).
4. Vojinovic, Z.; Keerakamolchai, W.; Weesakul, S.; Pudar, R.S.; Medina, N.; Alves, A. Combining ecosystem services with cost-benefit analysis for selection of green and grey infrastructure for flood protection in a cultural setting. *Environments* **2017**, *4*, 3. Available online: https://www.mdpi.com/2076-3298/4/1/3/htm (accessed on 9 July 2019). [CrossRef]
5. Alves, A.; Sanchez, A.; Vojinovic, Z.; Seyoum, S.; Babel, M.; Brdjanovic, D. Evolutionary and holistic assessment of Green-Grey infrastructure for CSO reduction. *Water* **2016**, *8*, 402. Available online: https://www.mdpi.com/2073-4441/8/9/402 (accessed on 9 July 2019). [CrossRef]
6. Zhao, H.; Zhao, J.; Li, X.; Zou, C. Role of Low-Impact developments in generation and control of urban diffuse pollution in a pilot sponge city: A Paired-Catchment study. *Water* **2018**, *10*, 852. Available online: https://www.mdpi.com/2073-4441/10/7/852 (accessed on 9 November 2018). [CrossRef]
7. Keesstra, S.D.; Kondrlova, E.; Czajka, A.; Seeger, M.; Maroulis, J. Assessing riparian zone impacts on water and sediment movement: A new approach. *Neth. J. Geosci.* **2012**, *91*, 245–255. Available online: https://www.cambridge.org/core/journals/netherlands-journal-of-geosciences/article/assessing-riparian-zone-impacts-on-water-and-sediment-movement-a-new-%20approach/62A646C5709A49E3CE6B38A39926A03B (accessed on 21 December 2018). [CrossRef]
8. Martinez, C.; Sanchez, A.; Galindo, R.; Mulugeta, A.; Vojinovic, Z.; Galvis, A. Configuring Green Infrastructure for Urban Runoff and Pollutant Reduction Using an Optimal Number of Units. *Water* **2018**, *10*, 1528. Available online: https://www.mdpi.com/2073-4441/10/11/1528 (accessed on 9 July 2019). [CrossRef]
9. Roy, A.H.; Wenger, S.J.; Fletcher, T.D.; Walsh, C.J.; Ladson, R.A.; Shuster, W.D.; Thurston, H.W.; Brown, R.R. Impediments and solutions to sustainable, watershed-scale urban stormwater management: Lessons from

Australia and US. *Environ. Manag.* **2012**, *42*, 344–359. Available online: https://link.springer.com/article/10.1007/s00267-008-9119-1 (accessed on 10 November 2018). [CrossRef] [PubMed]
10. Dutch Water Sector (DWS). Boskalis Contracted for Dutch Room for the River Project at Veessen-Wapenveld, the Netherlands. Dutch Water Sector. 4 July 2013. Available online: https://www.dutchwatersector.com/news/boskalis-contracted-for-dutch-room-for-the-river-project-atveessen-wapenveld-the-netherlands (accessed on 5 November 2018).
11. EPA. Healthy Benefits of Green Infrastructure in Communities. 2017. Available online: https://www.epa.gov/sites/production/files/2017-11/documents/greeninfrastructure_healthy_communities_factsheet.pdf#targetText=Green%20infrastructure%20installments%20also%20provide,overall%20health%20and%20well%2Dbeing (accessed on 5 November 2018).
12. Lawson, E.; Thorne, C.; Ahilan, S.; Allen, D.; Arthur, S.; Everett, G.; Fenner, R.; Glenis, V.; Guan, D.; Hoang, L.; et al. Delivering and evaluating the multiple flood risk benefits in blue-green cities: An interdisciplinary approach. *WIT Trans. Ecol. Environ.* **2014**, *184*, 113–124. Available online: https://www.witpress.com/elibrary/wit-transactions-on-ecology-and-the-environment/184/28342 (accessed on 12 December 2018).
13. Zhang, J.; Yu, Z.; Yu, T.; Si, J.; Feng, Q.; Cao, S. Transforming flash floods into resources in arid China. *Land Use Policy* **2018**, *76*, 746–753. Available online: https://www.sciencedirect.com/science/article/abs/pii/S0264837717314102 (accessed on 5 November 2018). [CrossRef]
14. World Bank Implementing Nature-Based Flood Protection: Principles and Implementation Guidance. 2017. Available online: http://documents.worldbank.org/curated/en/739421509427698706/%20Implementing-nature-based-flood-protection-principles-and-implementation-guidance (accessed on 21 December 2018).
15. Ruangpan, L.; Vojinovic, Z.; Di Sabatino, S.; Leo, L.S.; Capobianco, V.; Oen, A.M.P.; McClain, M.; Lopez-Gunn, E. Nature-Based Solutions for Hydro-meteorological Risk Reduction: A State-of-the-art review of the research area. *Nat. Hazards Earth Syst. Sci.* **2019**, under review. Available online: https://www.nat-hazards-earth-syst-sci-discuss.net/nhess-2019-128/ (accessed on 9 August 2019).
16. Alves, A.; Gersonius, B.; Kapelan, Z.; Vojinovic, Z.; Sanchez, A. Assessing the Co-Benefits of Green-blue-grey infrastructure for sustainable flood risk management. *J. Environ. Manag.* **2019**, *239*, 244–254. Available online: https://www.deepdyve.com/lp/elsevier/assessing-the-co-benefits-of-green-blue-grey-infrastructure-for-qnphUg7fuW?impressionId=5d059af1a1edf&i_medium=docview&i_campaign=recommendations&i_source=recommendations (accessed on 9 August 2019). [CrossRef] [PubMed]
17. Raymond, C.M.; Berry, P.; Breil, M.; Nita, M.R.; Kabisch, N.; de Bel, M.; Enzi, V.; Frantzeskaki, N.; Geneletti, D.; Cardinaletti, M.; et al. *An Impact Evaluation Framework to Support Planning and Evaluation of Nature-based Solutions Projects*; EKLIPSE Expert Working Group on Nature-based Solutions to Promote Climate Resilience in Urban Areas; Centre for Ecology & Hydrology: Wallingford, UK, 2017; Available online: http://www.eklipse-mechanism.eu/apps/Eklipse_data/website/EKLIPSE_Report1-NBS_FINAL_Complete-08022017_LowRes_4Web.pdf (accessed on 12 September 2018).
18. Thorne, C.R.; Lawson, E.C.; Ozawa, C.; Hamlin, S.L.; Smith, L.A. Overcoming uncertainty and barriers to adoption of Blue-Green infrastructure for urban flood risk management. *J. Flood Risk Manag.* **2018**, *11*, S960–S972. Available online: https://onlinelibrary.wiley.com/doi/full/10.1111/jfr3.12218 (accessed on 28 October 2018). [CrossRef]
19. Shinde, R.; Babel, M.S.; Suttharom, P. Manual on Framework for River Health Assessment in Thailand 2018. Asian Institute of Technology: Bangkok, Thailand. Available online: https://cgspace.cgiar.org/bitstream/handle/10568/92848/Frame%20work%20for%20River%20Health%20in%20Thailand.pdf?sequence=1&isAllowed=y (accessed on 5 November 2018).
20. RECONECT Project Objectives. Available online: http://www.reconect.eu/about-reconect/ (accessed on 6 November 2019).
21. Suksumek, T. Central Thailand. Weebly 2014. Available online: https://hgq2.weebly.com/central-region. https://hgq2.weebly.com/ (accessed on 18 November 2018).
22. Ditthabumrung, S. *Nature-Based Solutions for Water Management: A Case Study in The Rangsit Area, Thailand*; AIT Thesis No. WEM-18-08; Asian Institute of Technology: Bangkok, Thailand, 2018.
23. Carr, M.K.V. The Water Relations and Irrigation Requirements of Oil Palm (Elaeis Guineensis): A review. *Expl. Agric.* **2011**, *47*, 629–652. Available online: http://agris.fao.org/agris-search/search.do?recordID=US201500053138 (accessed on 22 October 2019). [CrossRef]

24. World Bank Group. Climate Data Historical Page. Available online: https://climateknowledgeportal.worldbank.org/country/thailand/climate-data-historical (accessed on 20 October 2019).
25. Tantivejkul, S. *Application of Science and Technology for Community Water-Related Disaster Risk Reduction*; Utokapat Foundation Under the Royal Patronage of H.M. the King; Hydro and Agro Informatics Institute (HAII): Bangkok, Thailand, 2016.
26. Huizinga, J.; de Moel, H.; Szewczyk, W. Global Flood Depth-Damage Functions. JCR Technical Reports 2017; European Commission. EUR 28552 EN. Available online: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC105688/global_flood_depth-damage_functions__10042017.pdf (accessed on 12 February 2019). [CrossRef]
27. Couto, T.B.A.; Zuanon, J.; Olden, J.D.; Ferraz, G. Longitudinal variability in lateral hydrologic connectivity shapes fish occurrence in temporal floodplain ponds. *Can. J. Fish. Aquat. Sci.* **2017**, *72*, 319–328. Available online: https://tspace.library.utoronto.ca/bitstream/1807/78869/1/cjfas-2016-0388.pdf (accessed on 2 September 2018).
28. The National Committee on Irrigation and Drainage (THAICID). 1999. Thailand. Available online: http://www.rid.go.th/thaicid/_5_article/article_body_1th.php (accessed on 23 November 2018).
29. Fornes, J.; Pirarai, K. Groundwater in Thailand. *J. Environ. Sci. Eng.* **2014**, *3*, 304–315. Available online: http://www.davidpublisher.org/Public/uploads/Contribute/55078898cb5e0.pdf (accessed on 23 November 2018).
30. Sydney Water Corporation. Stage—Primary Treatment; Wastewater Treatment Plant Virtual Tour. 2010. Available online: https://www.sydneywater.com.au/Education/Tours/virtualtour/html/primary-treatment.html (accessed on 18 November 2018).
31. Poomkhonsan, N.; Konyai, S. Land Use and Hydrologic Soil Group Classification for the Yang River Basin in Northeast Thailand. *KKU Eng. J.* **2013**, *40*, 473–483. Available online: https://www.tci-thaijo.org/index.php/easr/article/view/21735 (accessed on 25 November 2018).
32. Rawls, M.; Brakensiek, D.L.; Miller, N. Green-ampt Infiltration Parameters from Soils Data. *J. Hydraul. Eng.* **1983**, *109*, 62. Available online: https://ascelibrary.org/doi/pdf/10.1061/%28ASCE%290733-9429%281983%29109%3A1%2862%29 (accessed on 9 December 2018). [CrossRef]
33. Chavez, C. (USDA). Soil Infiltration Ability to Take in Water 2010 PowerPoint presentation. Available online: https://prod.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_068436.pdf (accessed on 8 December 2018).
34. Puttaso, A.; Vityakon, P.; Trelo-ges, V.; Saenjan, P.; Cadisch, G. Effect of Long-Term (13 Years) Application of Different Quality Plant Residues on Soil Organic Carbon and Soil Properties of Sandy Soil of Northeast Thailand. *KKU Res. J.* **2011**, *16*, 359–370. Available online: https://www.researchgate.net/publication/225968734_Relationship_between_residue_quality_decomposition_patterns_and_soil_organic_matter_accumulation_in_a_tropical_sandy_soil_after_13_years (accessed on 12 November 2018).
35. Zhang, W.; Dulloo, E.; Kennedy, G.; Bailey, A.; Sandhu, H.; Nkonya, E. Biodiversity and ecosystem services. In *Sustainable Food and Agriculture An Integrated Approach*; Campanhola, C., Pandey, S., Eds.; Academic Press: Rome, Italy, 2019; Chapter 8, pp. 137–152, ISBN 978-0-12-812134-4.
36. Lal, R. Carbon emission from farm operations. *Environ. Int.* **2004**, *30*, 981–990. Available online: https://www.sciencebase.gov/catalog/item/5140be35e4b06685e5db9794 (accessed on 21 December 2018). [CrossRef]
37. ESA. Sentinel-5P NRTI NO2: Near Real-Time Nitrogen Dioxide Data 2018. Available online: https://sentinel.esa.int/web/sentinel/user-guides/sentinel-5p-tropomi (accessed on 22 January 2019).
38. Delshammar, T. NBS Case Study: Malmo. Think Nature Platform Case Studies 2018. Available online: https://platform.think-nature.eu/nbs-case-study/19011 (accessed on 23 November 2018).