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1.00	$ 48,750.00	EA	0.00 %	$ 0.00		$ 0.00	$ 0.00	$ 48,750.00

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2nd payment for consulting services

Quantity	Unit Price	UOM	Discount %	Total Discount Amt.	Tax Rate	Tax Amount	Freight	Total Cost
1.00	$ 24,375.00	EA	0.00 %	$ 0.00		$ 0.00	$ 0.00	$ 24,375.00

Item # 3
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3rd payment for consulting services

Quantity	Unit Price	UOM	Discount %	Total Discount Amt.	Tax Rate	Tax Amount	Freight	Total Cost
1.00	$ 24,375.00	EA	0.00 %	$ 0.00		$ 0.00	$ 0.00	$ 24,375.00

TAX:	$ 0.00
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TOTAL:	$ 97,500.00

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THE TEXAS A&M UNIVERSITY SYSTEM TERMS AND CONDITIONS APPLY.

APPROVED

By: Patty Winkler
Email: p-winkler@tamu.edu
Phone#: (979) 845-4556

BUYER

RESEARCH AGREEMENT
BETWEEN
TEXAS A&M UNIVERSITY
AND
DELFT UNIVERSITY OF TECHNOLOGY

This RESEARCH AGREEMENT ("Agreement") is between TEXAS A&M UNIVERSITY, a member of The Texas A&M University System and an agency of the State of Texas, having a place of business at 200 Discovery Drive, College Station, Texas 77845, ("TAMU"), and Delft University of Technology with offices located at Stevinweg 1, 2628 CN Delft, The Netherlands ("TU Delft"), each of the aforementioned being referred to individually as the "Party" or collectively as the "Parties";

The research program ("Research"), contemplated by this Agreement is of mutual interest and benefit to the Parties, and will further the instructional and research objectives of TAMU in a manner consistent with its status as an agency of the State of Texas;

The Parties agree as follows:

1. STATEMENT OF WORK. TU Delft shall use its reasonable efforts to perform scientific research on "systems optimization." One of the key questions for Galveston Bay storm surge suppression is which combination of interventions will lead to an effective and acceptable risk reduction scheme. Interventions can include structural, non-structural and nature-based approaches. The result of this effort will be a modelling framework for systems optimization, which will be closely connected to ongoing research at the Center for Texas Beaches and Shores at Texas A&M University on the coastal spine and other surge suppression strategies. This is further described in the attached Appendix A. The statement of work shall not be changed except by written amendment to this Agreement signed by the Parties.

2. PROJECT DIRECTION. TAMU's Project Director is authorized to coordinate the technical aspects of the work within the general scope of work. The Project Director for this Agreement is Dr. Samuel D. Brody.

3. KEY PERSONNEL. TU Delft shall assign Dr. Bas Jonkman as Principal Investigator and key personnel for the work to be performed under this Agreement. No diversion or substitution of key personnel shall be made without the prior written approval of TAMU.

4. PERIOD OF PERFORMANCE. The work shall be conducted during the period commencing September 1, 2016 (the "Effective Date") and, unless earlier terminated in accordance with this Agreement, ending August 31, 2017 (the "Completion Date"). The Completion Date may be modified or extended only by written agreement of the Parties.

5. CONSIDERATION AND PAYMENT. As consideration for the work described in Article 1, TAMU shall pay TU Delft the fixed price amount of $97,750 in U.S. dollars in accordance with the budget

appended and incorporated as Appendix B. For purposes of this Agreement an exchange rate of 1 Euro = $ 1.15 has been assumed. Payments shall be made to TU Delft by TAMU on the following basis:

50% due upon execution of the Agreement and receipt of invoice
25% due half way through the project (March 1, 2017) upon receipt of proof of concept technical report (phase 1)
25% due on the last day of the project

Invoices shall be consistent with the billing format attached and incorporated as Appendix C. Payment of invoices shall be contingent upon approval by Project Director. The final invoice shall be marked "Final," and shall be received no later than sixty (60) days after the completion date in Article 4. TU Delft shall submit invoices via email to:

Texas A&M University Galveston Campus
P.O. Box 1675
Galveston, TX 77551

Attn: Sherry Parker, parkers@tamug.edu
Tammy Holliday, hollidat@tamug.edu

Checks should be made to TU Delft and payment forwarded to the following address:

P.O. Box 5048
2600 GA Delft The Netherlands
ATTN: P.Y. (Petra) Jorritsma

6. DELIVERABLES. TU Delft shall furnish TAMU with deliverables and reports as specified in Appendix A.

7. TERMINATION. Either party may terminate this Agreement by giving forty five (45) days advance written notice to the other party. TAMU shall pay the Agreement price, if separately stated, for completed work it has accepted, and the amount agreed upon by TU Delft and TAMU for completed work for which no separate price is stated, or for partially completed work. In no event, however, shall payments to TU Delft under this provision exceed the fixed-price amount authorized in Article 5. After such termination, TU Delft shall promptly submit to TAMU copies of all data, draft reports, and any other information related to the work performed under this Agreement.

8. INTELLECTUAL PROPERTY.

A. "Intellectual Property" means all intellectual property, including without limitation, electronic or otherwise, technical information, know-how, copyrights, patents and trade secrets, ideas, thoughts, concepts, processes, techniques, data, development tools, models, drawings, specifications, prototypes, inventions and software.

B. "Project IP" or "Project Intellectual Property" shall mean all Intellectual Property that is authored or conceived and reduced to practice in the performance of the Research.

C. Ownership of Project IP shall be as follows:

(i) Title to any Project IP made or conceived solely by employees of TAMU vests in TAMU.

(ii) Title to any Project IP made or conceived solely by employees of TU Delft vests in TU Delft.

(iii) Title to any Project IP made or conceived jointly by employees of both TAMU and TU Delft (hereinafter called "Joint IP") vests jointly in TAMU and TU Delft.

D. TU Delft shall promptly disclose all Project IP and Joint IP in sufficient detail as to allow TAMU evaluation ("Invention Disclosure"), and TAMU shall have a reasonable time option to negotiate a license to TU Delft's interests in such disclosed Project IP. Any such Invention Disclosure shall be considered Confidential Information.

E. For Joint IP conceived under this Agreement, TAMU and TU Delft will be independent owners of any corresponding patent rights under 35 USC 262 with no obligation of accounting to one another, in the absence of a written agreement to the contrary.

9. CONFIDENTIAL INFORMATION. All information furnished to TU Delft by TAMU under this Agreement shall be considered confidential. TU Delft agrees that it will keep confidential and not disclose, disseminate or publish any information, computer programs or software furnished to TU Delft by TAMU for the work to be performed under this Agreement, and will use such items/information only in the performance of this Agreement. The TAMU has determined that the information/data that the TU Delft will be provided during the performance of this Agreement is of a sensitive nature and cannot be disclosed in any manner. Each TU Delft employee with access to the information/data under this Agreement shall sign an agreement agreeing to the confidentiality terms of this Agreement. Whenever TU Delft is uncertain with regard to the proper handling of information/data under this Agreement, TU Delft shall obtain a written determination from the TAMU Representative listed in Article 11. Upon the completion of this Agreement, TU Delft shall return all such items/information to TAMU, or make such disposition as may be directed in writing by TAMU.

10. PUBLICATIONS. TAMU may publish the results of the Research, except for TU Delft's Confidential Information, after providing the TU Delft with a 30 day period in which to review each publication to identify patentable subject matter and to identify any inadvertent disclosure of Confidential Information. If necessary to permit the preparation and filing of U.S. patent applications, TAMU may agree to an additional review period not to exceed 60 days. Such delay shall not, however, be imposed on the filing or publication of any student thesis or dissertation. Failure to respond within 30 days shall constitute de

facto agreement of TU Delft that no delay in publication is necessary. Any further extension will require agreement between the TU Delft and TAMU.

11. NOTICES. All notices to Parties under this Agreement shall be in writing and sent to the names and addresses stated below under NOTICES. Either Party to the Agreement may change such name and address by notice to the other in accordance herewith, and any such change shall take effect immediately upon receipt of such notice.

NOTICES to TAMU:

Office of the Vice President for Research
200 Discover Drive
College Station, TX 77845-2403
Attn: Lesa Feldhousen
Telephone: 979-862-7986
Email: lfeldhousen@tamu.edu

NOTICES to TU Delft:

Delft University of Technology
Faculty of Civil Engineering and Geosciences
Stevinweg 1
2628 CN Delft, The Netherlands
Attn: Petra Jorritsma
Telephone: +31 15 2787766
Email: p.y.jorritsma@tudelft.nl

12. EXPORT CONTROLS. TU Delft shall not, nor shall TU Delft authorize or permit its employees, agents or lower tiers to disclose, export or re-export any TAMU information, or any process, product or services produced under this Agreement, without prior notification to TAMU and without complying with all applicable United States Federal, state and local laws, regulations and ordinances, including the regulations of the United States Department of Commerce and/or the United States Department of State. In addition, TU Delft agrees to immediately notify TAMU if TU Delft's employees performing work under this Agreement are listed on any of the United States Department of State, Treasury or Commerce proscribed persons or destinations lists, or if TU Delft's export privileges are otherwise denied, suspended or revoked in whole or in part.

13. INDEPENDENT CONTRACTOR. For the purposes of this Agreement and all services to be provided hereunder, the Parties shall be, and shall be deemed to be, independent contractors and not agents or employees of the other Party. Neither Party may make any statements, representations, or commitments of any kind, or take any actions which are binding on the other Party, except as may be explicitly provided for herein or authorized in writing.

14. DEBARMENT AND SUSPENSION.

In accepting this Agreement, TU Delft certifies that it and its principals:

(a) are not presently debarred, suspended, proposed for debarment, declared ineligible or voluntarily excluded from participation in this transaction by any Federal department or agency. Any change in the debarred or suspended status of TU Delft during the life of this Agreement must be reported immediately to TAMU.

(b) have not within a three year period preceding this Agreement been convicted of or had a civil judgment rendered against them for commission of fraud or a criminal offense in connection with obtaining, attempting to obtain, or performing a public (federal, state, or local) transaction or contract under a public transaction: violation of Federal law or State antitrust statutes or commission of embezzlement, theft, forgery, bribery, falsification or destruction of records, making false statements, or receiving stolen property.

(c) are not presently indicted for or otherwise criminally or civilly charged by a government entity (federal, state or local) with commission of any of the offenses listed in paragraph (b) of this article.

(d) have not within a three year period preceding this Agreement had one or more public transactions (federal, state, or local) terminated for cause or default.

15. SEVERABILITY. If any of the provisions of this Agreement is rendered or declared illegal for any reason, or shall be invalid or unenforceable, the remainder of this Agreement shall remain in full force and effect if the essential terms of this Agreement remain, valid, legal, and enforceable.

16. ASSIGNMENT. This Agreement may not be assigned in whole or in part by any of the Parties without prior written consent of the other Party, except to a successor to all or substantially all of its business and assets.

17. PUBLICITY. Neither Party may use the names of the other Party, nor of any of its employees or members, nor any adaptation thereof, in any advertising, promotional or sales literature or news release without the prior written consent obtained from the other Party, as applicable in each case.

18. HEADINGS. The headings used herein are for reference and convenience only and shall not enter into the interpretation hereof.

19. DISPUTE RESOLUTION. In the event of any dispute arising between the parties concerning this agreement, its enforceability or the interpretation thereof, the parties shall try to settle those conflicts amicably between themselves. Should they fail to agree within a period of two (2) months from the date on which the one party first notified the other party of the conflict, then either party may elect to pursue the legal remedies available in law or equity.

TAMU is an agency of the State of Texas and nothing in this Agreement waives or relinquishes TAMU's right to claim any exemptions, privileges, and immunities as may be provided by law.

20. FORCE MAJEURE. Neither Party shall be liable for any unforeseen event beyond its reasonable control not caused by the fault or negligence of such Party, which causes such Party to be unable to

perform its obligations under this Agreement and which it has been unable to overcome by the exercise of due diligence. Such unforeseen events include, but are not limited to, fire, storm, flood, earthquake or other natural catastrophes, accidents, acts of civil disturbance or disobedience, war, rebellion, insurrection, labor strikes or disputes, compliance with any laws, requirements, rules, regulations, or orders of any governmental authority or instrumentality thereof, sabotage, invasion, quarantine, and embargoes, or because of any act of God.

21. CONFLICT OF INTEREST. TU Delft shall have written policies and guidelines on conflict of interest and avoidance thereof. Collaborator certifies that, to the best of its knowledge upon reasonable inquiry, conflicts of interest do not exist for individuals participating in the project supported under this Agreement. Should this situation change during the time of this Agreement, TU Delft shall promptly advise TAMU of such change.

22. INDEMNIFICATION. At all times during and after termination of this Agreement, to the extent allowed by law, TU Delft shall indemnify, defend and hold harmless TAMU, The Texas A&M University System, its regents, officers and employees and affiliates against any claim, proceeding, demand, liability, or expenses (including legal expenses and reasonable attorney's fees) which relates to injury to persons or property or against any other claim, proceeding, demand, expenses and liability of any kind arising out of or in connection with this Agreement, except to the extent that such loss, claim, damage or other liability arises in whole or in part from the negligence of TAMU.

23. RECORDS, AUDITS AND ACCESS.

Records: TU Delft shall maintain financial and other records related to this Agreement for a period of not less than three (3) years from the conclusion of the Agreement. TAMU and/or its authorized representatives, shall have the right to examine and copy said records for any lawful purpose.

Audit and Access: With specific reference to this Agreement, TAMU reserves the right to request copies of audit reports from audits conducted by/for the TU Delft. TAMU and/or its duly authorized representatives, shall have the right to conduct site visits and audits, meet with project participants, and view any materials, equipment or supplies purchased under this Agreement. Audit visits will be scheduled in cooperation with TU Delft. Site visits can be more spontaneous, but will be conducted during normal business hours. The TU Delft shall take all necessary steps to ensure TAMU and/or its authorized representatives, are granted access as specified in this Article. Failure to provide reasonable access shall constitute a material breach in this Agreement and may, at the sole discretion of TAMU, result in the immediate suspension or termination of this Agreement.

24. GOVERNING LAW. The validity, interpretation, and enforcement of this Agreement shall be governed and determined by the laws of the State of Texas without regard to its conflicts of laws principles, and venue for any action brought hereunder shall be in Brazos County, Texas.

25MISCELLANEOUS.

Parties make no warranties, express or implied, as to any matter, including, without limitation, warranties as to the conduct, completion, success or particular results of the research, or the

condition, ownership, merchantability, or fitness for a particular purpose of the research results or any intellectual property or that the use of any intellectual property or research results will not infringe any intellectual property right of a third party. Parties shall not be liable for any direct, indirect, consequential, punitive or other damages suffered by sponsor or any other person resulting from the research or the use of any intellectual property or research results.

This Agreement constitutes the entire agreement between the parties relative to the subject matter, superseding and cancelling all previous, all prior and contemporaneous oral or written agreements, discussions or understandings related to the subject matter, and may be modified or amended only by a written amendment signed by both parties.

This Agreement will not be assigned, in whole or in part, by either party without the prior written consent of the other party. Any attempt to do so shall be void.

This Agreement is binding upon and will inure to the benefit of the parties, their representatives, successors in interest and permitted assigns.

The failure of either party at any time to require performance by the other party of any provision of this Agreement will in no way affect the right to require such performance at any time thereafter nor will the waiver by either party of a breach of any provision be taken or held to be a waiver of any succeeding breach of such provision or as a waiver of the provision itself.

If any provision of this Agreement is held to be invalid, illegal or unenforceable, then such provision will be severed and will not affect the remainder of this Agreement.

The Parties have caused this Agreement to be executed by their authorized representative.

Texas A&M University

for By: _____
Name: Carol J. Cantrell
Title: Senior Associate Vice President
for Research Administration

Date: 9/20/16

Delft University of Technology

By: _____
Name: Prof. Dr. Ir. B.M. Geerken

Title: Dean Faculty of Civil Engineering and Geosciences

Date: 12/9/2016

Appendix A

Statement of Work

Appendix: Multiple Lines of Defense Systems optimization – application to the Houston - Galveston region

Background and rationale

The Galveston Bay area is at significant risk from hurricane-induced flooding. Over the past years extensive research has taken place on possibilities of flood risk reduction in and around the Galveston Bay, for example with the construction of a coastal spine, a storm surge barrier in the Houston ship channel and/or wetlands in the bay. Given the complexity of the surge hazard and the geographical risk profile, it is likely that a strategy consisting of multiple lines of defense will be required for the region. Some individual features (e.g. coastal spine, mid bay barrier, Houston ship channel barrier) have been designed at varying levels of detail. However, the question remains which combination of interventions will be most effective in reducing the risk for the region, as well as socially most acceptable.

In ongoing studies by SSPEED and the coastal spine group the underlying building blocks of such a risk-based optimization are being elaborated (such as hurricane surge, damages and interventions). However, no fully integrated model has been developed yet which combines these findings in order to quantify the flood risk (reduction) for a given system configuration. In order to quantify benefits of any intervention, risk reduction benefits would have to be calculated. In such an analysis, the risk in the current (do nothing) situation would be compared with residual risk under various system interventions.

Since the existing models for surge, damage and land use are already complex by themselves[1], it is proposed to develop a simplified risk model that could be used to evaluate various interventions and system configurations. It would integrate and couple outcomes of the hurricane, damage and intervention studies. This type of model framework has also proven to be very beneficial for New Orleans and other situations (see also the game plan (2014)). The approach would also be based on experiences with decision-making on and optimization of large-scale coastal interventions in the Netherlands. The Dutch experiences are limited to optimization for single and given interventions (i.e. dike reinforcement). In the Galveston Bay a more complex optimization will be required that assesses the combined effects (and costs) of multiple interventions. TU Delft will develop a systems optimization model that can facilitate the consideration of various interventions in Galveston Bay. This document will outline the project objectives (section 2), research approach (section 3) and project organization (section 4).

[1] The alternative is to couple existing sets of (complex) models for surge and economic impact. Since a probabilistic approach is needed with many scenarios, coupling existing complex models would likely result in model framework that is less suitable to evaluate various system configurations relatively quickly.

Project objectives

The aim of the proposed project is to develop a risk-based optimization framework to assess the different (combinations) of interventions based on costs, surge and risk reduction in a bay. The framework will be applied to proposed sets of interventions in the Galveston Bay to find the optimal "multiple lines of defense" strategy for the Houston Galveston region.
A method will be developed that is capable of optimizing combinations of interventions and prioritize these based on costs and economic risk reduction. Other aspects such as societal and environmental impacts will be discussed qualitatively and ranked with other indicators. The method is called MODOS (Multiple lines of Defense Optimization System) and will be set up in a generic way so that it is capable of handling different interventions with different effects (e.g. barriers, levees, wetlands, non-structural, modifications of structures and buyouts). Also, it is envisaged that the MODOS approach should be applicable to other regions around the world with similar questions (e.g. Rotterdam Rijnmond, Shanghai etc.), but these other cases are outside of the scope of this project – although related initiatives will be encouraged to test the approach for other cases.
It is noted the proposed research will also cover an important scientific challenge. Although recent research has addressed multiple lines of defense systems in a risk framework (Custer, 2015; Tsimopoulou et al., 2014; Dupuits et al., 2015), a thorough approach for evaluation and optimization of these complex systems is not available yet.

Multiple lines of defense optimization: approach

This chapter described the anticipated approach for the development of the systems optimization / MODOS modelling framework. Depending on findings during the first phases of the project, parts of the approach might be adapted.

General approach

Risk is considered as the product of flood frequency (per year) and flooding consequences. Here, the economic risk is considered, although life loss can be added at later stage. In order to determine the risk for a given multiple lines of defense system configuration, insight is needed in the (return periods of) hydraulic loads at various locations, effects of interventions and potential damages (see figure 1). Given the complexity of Galveston Bay a large number of (combinations of) interventions will be possible. One of the key challenges is to reduce the number of combinations to reduce calculation burden. A combination of inputs and techniques including (probabilistic) surge modeling, cost information, fragility curves, damages studies and GIS approaches will be needed to "feed" the optimization model. Therefore, extensive collaboration with research partners will be required and TU Delft will "schematize" available information from other studies into the optimization system. The proposed research steps are discussed in more detail in the next section.

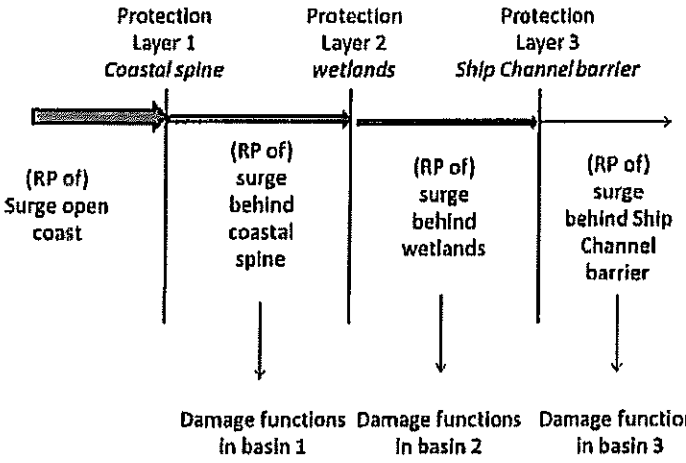

Figure 1: Schematic representation of a multiple lines of defense system

Given the complexity of the optimization, the project will be implemented in two phases. In stage 1, a proof of concept of MODOS will be developed with a simplified case with similarity to the Houston Galveston Bay. Existing information, assumptions and expert judgment will be used, and the model will be implemented for a limited number of interventions (e.g. three). In the second phase the optimization system will be applied to the Galveston Bay with more realistic information. In this phase we will heavily rely on specific inputs from JSU and other partners. Available information will be included in a schematized way in the model framework, but TU Delft will do no additional surge or damage modeling. However, key issues or points for improvement uncovered while applying these models will be identified and reported.

Research steps and activities

The development of the optimization framework will require research in the field of hydraulic modeling, flood damage assessment, cost functions and economic optimization. The following bullets discuss the key components of the optimization framework (also see fig. 1 and fig. 2 for the more detailed steps and functions):

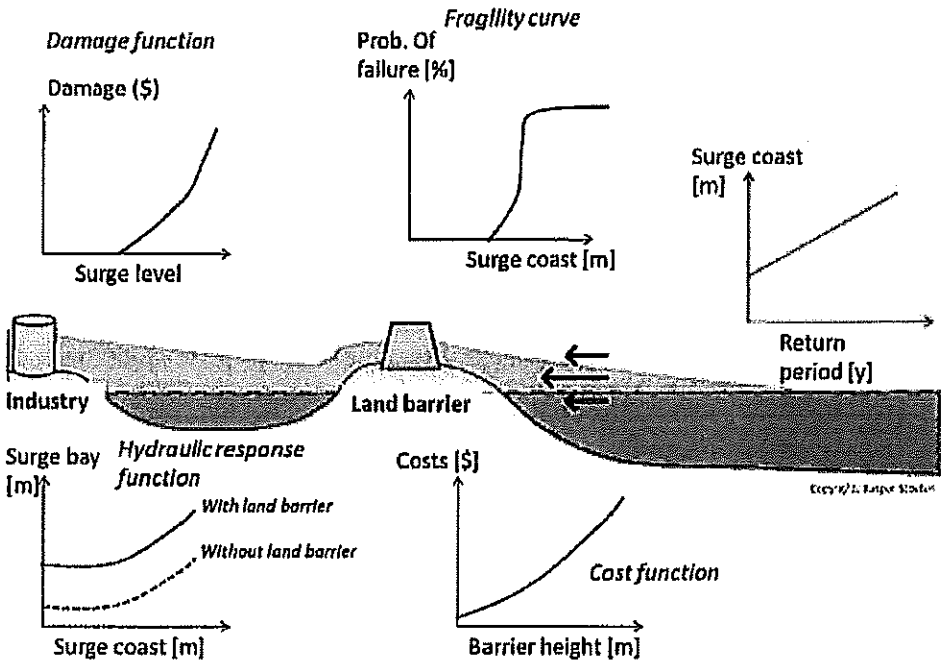

Figure 2: Schematic overview of steps and functions used in the risk determination for a given system configuration (example with and without land barrier).

Step 1: System characterization

For a given system configuration – i.e. in the current situation or with a series of interventions implemented – the system is schematized according to figure 1. Using the outcomes of more complex models (e.g. for surge, damage) the system will be schematized into a limited number of basins, and for each basin a limited number of characteristic locations will be analyzed to find relationships between surge, damages, and study the effects of interventions. A certain basin can be protected by multiple lines of defence. For example, the industry in the Houston Ship Channel could be protected by a coastal spine, wetlands in the bay and a surge barrier in the Ship Channel (See fig. 1).

The risk and risk reduction for a given system will be analyzed using the following steps (2 – 5). In step 5 various system configurations will be compared and analyzed.

Step 2: Characterization of hydraulic loads on the open coast

The goal is to determine return periods of water levels at the open coast and inside the bay (as a function of interventions):

- Open coast: calibration and validation of return periods of water levels at the open coast, based on the work by JSU and UT Austin, also the work based on Stoeten's thesis (2013) and work by Dupuits and Sebastian (2015, to be published) could be utilized.
- Inner bay: determine effects of open coast (coastal spine) and inner bay (wetlands) interventions on the return periods of water levels by means of a response function. In collaboration with JSU and UT Austin it will be determined what the water levels will be behind a certain intervention (e.g. a storm surge barrier) as a function of the loads on that intervention.

Step 3: Cost, fragility and response functions: develop cost functions of different interventions as a function of their main design variables. Various types of interventions have different effects on risk and remaining probability of surge behind the intervention. The following typology could be used (and further extended where necessary):

  - Storm surge barriers (e.g. bolivar roads): these prevent inflow for situations above closure water level. There is a small probability of failure due to non-closure or structural failure.
  - Levees / dikes: will generally provide protection up to a certain level and then fail. Some levees could be "overflow resistant" to a certain level
  - Wetlands and reefs: reduce the waves, set up and hydraulic loads.
  - Damage mitigation: raising flood plains, land use planning, adapting buildings etc. These will affect the relationship between water levels and damages.
- Various sets of parametric functions will be used to assess the effect of interventions on risk reduction (see also fig. 2):
  - Cost functions: used to characterize the costs for a given system configuration. Unit cost estimates are available at TU Delft for a wide variety of coastal interventions (barriers, levees, wetlands)
  - Fragility curves: for every type of interventions, typical fragility curves will be derived that express the conditional probability of failure as a function of the load level. TU Delft will derive typical fragility curves for various features.
  - (Hydraulic) response functions: for a given set of interventions, these functions express the relationship between the water level in a certain basin (e.g. in the bay) and the water level outside (e.g. on the ocean). Results of hydraulic modeling by JSU and SSPEED will be utilized to establish these hydraulic response functions.

Step 4: Flood damage assessment:

The aim of this step is to develop damage functions for both the direct (material) damages and indirect (business loss) damages in different areas / basins as a function of occurring water levels and their return periods. Previous studies by Texas A&M, SSPEED and UoH will be used to characterize damages in a certain region as a function of flood water levels with so-called damage functions that relate the level of economic damage to the surge that is occurring. Collaborating with these researchers, TU Delft will develop damage functions for larger geographical regions (basins).

Step 5: Risk modelling and determination

By combination of the previously identified elements, the return periods of damages for a given system configuration can be established. Simply said, the return period of surge in basin 1 (e.g. the coast) will be transferred using the fragility and hydraulic response curves for establishing the return period of surge in basin 2. By coupling the surge level with the damage function, an expected economic damage ($/year) for a given configuration can be obtained.

The calculation approach (see fig. 2) will be implemented in a flexible computational framework. This model can implement different interventions, functions (cost, response and fragility curves). Probabilistic techniques (e.g. Monte Carlo, importance sampling) will be used to be able to determine the overall risk for events with different return periods. The relationships, functions and inputs that will be included in the model will be based on the more detailed and complex studies that are ongoing by groups like JSU, TAMUG, SSPEED etc.

Step 6: Alternative evaluation and risk-based optimization

The final step of the application consists of two (sub) analyses.

The first concerns the generation of alternatives. Given the large number of single interventions and elements, a very large number of system configurations can be created. Working with stakeholders a starting set of logical initial strategies will be created. Following from the first evaluation runs insight will be gained in the sensitivities of the outcomes for certain design choices. As a result new logical and promising combinations of interventions will be determined. For every system configuration the risk model (step 2 – 5) will be used.

Also, within the design of a single intervention or strategy (e.g. design dike height or a coastal spine) different choices will be explored. Tradeoffs and optimizations between design choices will be highlighted (see fig. 3 and 4 for examples).

The use of various optimization techniques, such as GA (genetic algorithm) optimization and 0-1 integer programming, will be investigated to model a large number of strategies.

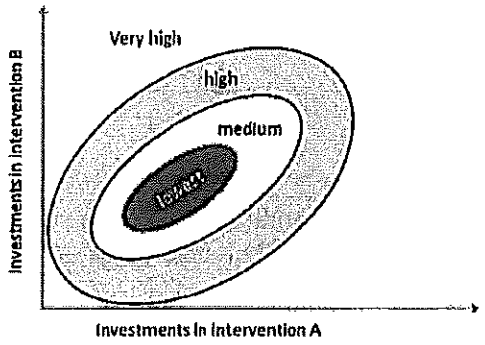

Figure 3: Conceptual example of tradeoffs and optimization. Figure shows the total costs (investments + risk) for a combination of interventions. The optimal configuration is found in the blue ellipse.

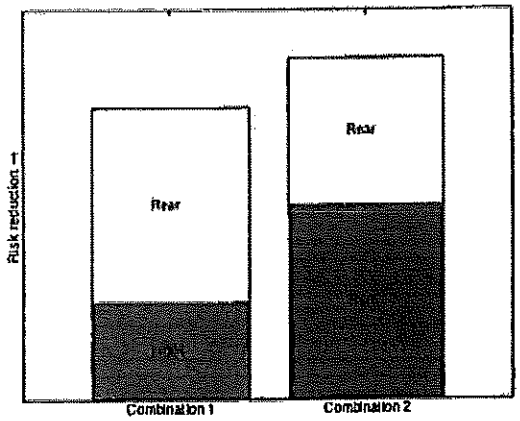

Figure 4: Conceptual example showing the risk reduction for two combinations of interventions with protection on the front (or outside) and rear (or inside). Both combinations have a similar investment cost, however combination 2 leads to a larger risk reduction.

The second sub-step concerns the determination of benefit (risk reduction) and cost ratios of the various strategies. Strategies can be ranked according to different parameters, e.g. risk reduction, benefit / cost ration, or other decision rules (e.g. mini-max etc.). Eventually, this will give insight in what the optimal multiple lines of defense strategy for the region will be according to different decision perspectives.

As an additional exploration, additional features of the strategies could be evaluated using multi-criteria analysis and / or ranking. For example, ecological and environmental or social impacts of strategies could be highlighted in a more qualitative way and thereby also be incorporated in the evaluation process. This will be done working with local stakeholders.

Project organization

Research team

The research team will consist of a (new) postdoctoral researcher[2] at TU Delft with expertise in optimization, civil engineering, and risk analysis. The researcher will work full time on this assignment and will be guided by professors Jonkman and Kok (flood risk) at the hydraulic engineering

[2] The staffing and salary costs for the researcher position will depend on the availability of high-quality researchers. If a more junior researcher will perform tasks, the remaining funds will be used for other research tasks within the systems optimization project, such as programming etc.

department at TU Delft and will work closely with the other researchers at TU Delft that are working on the "Texas case" and who will be involved for specific "modules" of this project. The researcher will work in close collaboration with Jonkman and the liaison for the collaboration, dr. Bee Kothuis. Close collaboration and interaction is foreseen on the following topics with a number of groups:

- Surge modeling: JSU and UT Austin
- Proposed Interventions: SSPEED, TAMUG (and colleagues at TU Delft)
- Damage studies: TAMUG and University of Houston

Planning

An updated work plan (an updated version of this document) will be delivered 1 month after project initiation.

The project will be executed in two stages. In stage 1 a proof of concept of MODOS will be developed with a simplified case with similarity to the Houston Galveston Bay. Existing information, assumptions and expert judgment will be used, and the model will be implemented for a limited number of interventions (e.g. three).

The duration of phase 1 will be 6 months after project initiation and start of the postdoc.

In the second phase, the optimization system will be applied with more realistic information. The duration of this phase is expected to be around up to12 months, extending into year 2. Close collaboration with research partners is foreseen, and various interactions mechanisms will be utilized. These include: a shared data platform, Skype / conference calls, joint workshops and working visits to institutes to collect and share information and discuss schematizations applied. The primary contact person at Texas A&M Galveston will be dr. Samuel Brody. Project team members will participate in quarterly conference calls with Texas A&M Galveston, to be organized by the coordination / liaison at TU Delft

The project will start on Sept 1, 2016; or at a later date if contracting starts later.

Deliverables

The following deliverables will be prepared:

- Work plan (phase 0): 1 month after project initiation
- Proof of concept technical report (phase 1); 6 months after project initiation.
- Final technical report (phase 2): Multiple lines of defense optimization – initial application to Galveston Bay – report after 12 months documenting results and findings at that time (for a complete realistic optimization a longer duration than 1 year is anticipated)

Moreover, the computational framework program (and the source code) developed by the research team during the project will be available to all the partners in this research. Deliverables of the research project will also consist of several (joint) scientific publications discussing the development and implementation of the risk-based optimization framework for the Houston Galveston bay area.

Appendix B

Budget

Activity		Costs (Euro)	Costs ($)*	Comment
Postdoc researcher	1 fte	€ 75.000	$86.250	New Postdoc recruited
Senior staff	15 mandays	€ 10.000	$11.500	Jonkman and others
Master students research + supervision				Jonkman and others
Total		**€ 85.000**	**$97.750**	

*An exchange rate of 1 Euro = $ 1.15 has been assumed. Changes in the exchange rate are at the risk of TU Delft. The proposed costs do not include VAT and travel and lodging costs.

Appendix C
Billing Format

Remit To:
Subawardee Name
Address
Address
City, State Zip
Current Billing Period: XXXXXXXX – XXXXXXXX

Invoice Date:
Invoice No.:
Subaward No.:
TAMUS Account No.:
Subawardee Tax ID No.:

Final Billing (Including Final Indirect Cost Rate): ___Yes ___No

Major Cost Elements	Approved Budget	Expenditures for Current Billing Period	Cumulative Expenditures from Inception
Salaries and Wages	$	$	$
Fringe Benefits	$	$	$
Total Direct Costs	$	$	$
Total Costs	$	$	$

CERTIFICATION:

I certify to the best of my knowledge and belief that the billed costs are in accordance with the terms and conditions of the Agreement and that payment is due and has not previously been requested. I further certify that administrative/clerical salaries, office supplies, postage, or membership fees have not been claimed without approved justification.

_____ _____
Name: Date
Title:

Please call _____ at (___) ___-_____ or email _____ if you have any questions.

FOR TAMUG USE ONLY:
APPROVALS:

I certify these costs were incurred to conduct research for the referenced TAMUS account number and are properly chargeable to the account. All deliverables or reports required to date have been received and are acceptable. The work is currently on schedule and I am not aware of any delays or potential delays.

_____ _____
Principal Investigator Date

_____ _____
Department Head Date

Appendix D

**[General Provisions
or other relevant attachments
as necessary]**