Coastal Dynamics 2013
Paper No. 110

UNCERTAINTY, RESEARCH, SCIENCE AND ENGINEERING IN COASTAL DYNAMICS

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Abstract

This paper develops a model for understanding uncertainties in coastal dynamics and analyzes our definitions and methodologies of coastal research, science and engineering against this model. It examines the different research cultures of academia and practice and identifies the need for more co-operation between these two, in order to be able to advance the understanding of how to apply basic science to complex, large-scale problems in coastal dynamics. The aim of the paper is to provide some guidance for the future against historical background and probable trends in research financing.

Key words: Coastal dynamics, engineering, research, research funding, science, uncertainty

1. Introduction

This paper first develops a better understanding of uncertainty in coastal dynamics and it proposes a conceptual model to describe uncertainty, here called the Uncertainty Trumpet. From there, the paper proceeds to analyze our definitions and methodologies of coastal research, science and engineering against this conceptual model. This is followed by a discussion of two research cultures in coastal dynamics – academia and practice. The need for greater co-operation between the two cultures is identified, in order to be able to advance our understanding of how to apply basic science to complex large-scale problems in coastal dynamics. Two simple examples are provided, based on the author's research, to illustrate the needs and difficulties involved in bridging the present gap between science and application, between theory and practice. The paper ends with conclusions drawn from the discussion and hopes to provide some guidance for the future based on this historical background and on possible trends in research financing. Note: Coastal Dynamics research takes place all over the world but research trends and history differ from jurisdiction to jurisdiction. Hence, this paper can only point to some common, general trends and may not apply to your particular situation.

2. Uncertainty

Uncertainty increases with the complexity of the coastal processes, as in Figure 1. This growth of uncertainty is called the 'Uncertainty Trumpet' in this paper. Such a curve was first proposed in Kamphuis (2005) and (2006) as a conceptual description of uncertainties around the design of a proposed island airport off the Dutch coast.

The Uncertainty Trumpet relevant for Coastal Dynamics is shown in Figure 2. There are other such trumpets that could be drawn for coastal dynamics, but Figure 2 is the most relevant for this conference. The trumpet is continuous, but in the diagram it has been artificially subdivided into two regions (above and below the X-axis) and four zones for ease of reference and identification.

The complexity (and therefore the uncertainty) of a problem increases with the (space and time) scale of the process and with the number of interacting processes. Figure 2 demonstrates this. Below the X-axis,

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the effect of scale is isolated for fluid flow, the prime driver for coastal dynamics. Above the X-axis the effect on uncertainty of the both scale and interaction of two basic processes, the interaction of fluid flow and sediment, is shown.

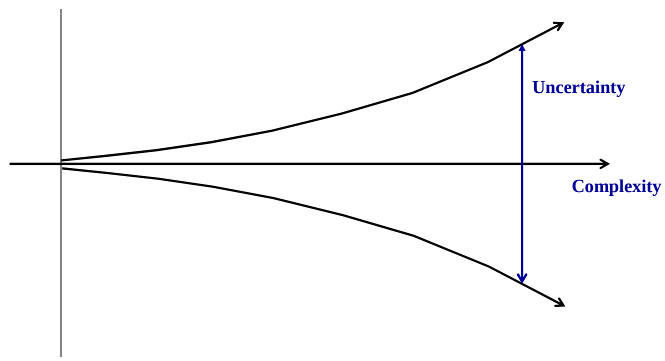

Figure 1 UncertaintyTrumpet

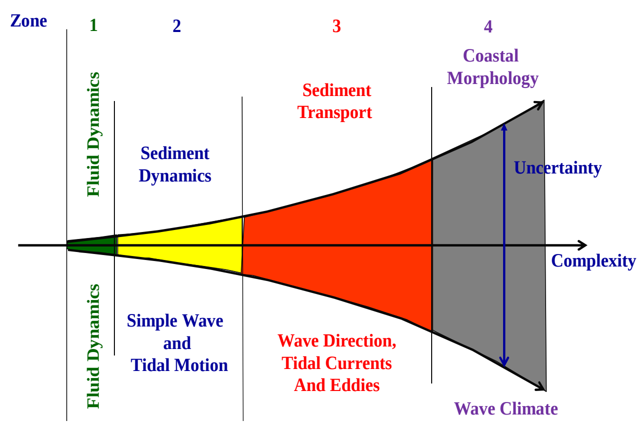

Figure 2 Uncertainty Trumpet for Coastal Dynamics

Figure 2, states that, near the origin, basic fluid dynamics (measurements, research and calculations) contain a relatively small amount of uncertainty. This uncertainty increases with space and time scales as shown in the bottom half of the figure for fluid flow.

The interaction of the fluid flow with sediment, shown in the top half of Figure 2 is not a straightforward, linear process. Consider the number of additional drivers that exist to determine sediment dynamics. Grain size, shape and density, grain-grain interactions, bedforms, fluid-grain interactions, etc. must all be considered. The fluid driving forces must also be expressed as functions of aggregate (representative) fluid flow properties. For example, detail fluid properties, such as local velocities, accelerations and shear stresses are replaced by general concepts, such as wave height and period, water depth, etc. As a result, sediment dynamics contains substantially greater uncertainties than fluid dynamics.

The detailed fluid flow and sediment dynamics must be further integrated over larger space and time scales to determine sediment transport. This integration involves further averaging with assumptions and simplifications. For example, local wave parameters are now represented by longer-term concepts, such as distributions of wave height, period and direction, wave spectra, etc. The uncertainties in larger-scale wave and current patterns and sediment transport patterns are also greater than for research on sediment dynamics.

Coastal morphology involves further integration of wave and tide motion and sediment transport. It is, for example, necessary to consider wave climate instead of waves. These additional assumptions and the greater averaging, increase uncertainties once again.

3. **Research**

3.1 Different Types of Research

It is possible to develop an understanding of coastal dynamics research, science and engineering against the background of the Uncertainty Trumpet. Research[2] takes place throughout the whole Uncertainty Trumpet, but the increase in uncertainty with complexity causes the characteristics of the research in each of the zones to be quite different. Research in Zones 1 and 2 of Figure 2 generally involves detail, small scale processes with relatively precise formulations. Research in Zones 3 and 4 involves integral (aggregate) processes over larger time and distance scales, with greater complexity. Research in Zones 1 and 2 consists mainly of measurement and analysis of basic fluid and sediment processes. Research projects in Zones 3 and 4 involve synthesis of the concepts discovered by the more basic research in the previous zones, and the application of these synthesized concepts to understanding complex, aggregated systems. The common tool to help with both the understanding of the processes and with the synthesis of the concepts is simulation – physical modeling and now mostly numerical modeling. To validate such synthesized results, research in Zones 3 and 4 also involves measurement and analysis, but of more complex aggregate physical processes in waves, currents, sediment transport and coastal morphology.

Thus, research throughout the Uncertainty Trumpet involves analysis, (or science), but research in Zones 3 and 4 also involves synthesis of more basic processes. This synthesis is Applied Science and if it leads to design it is Engineering. This is summarized in Figure 3.

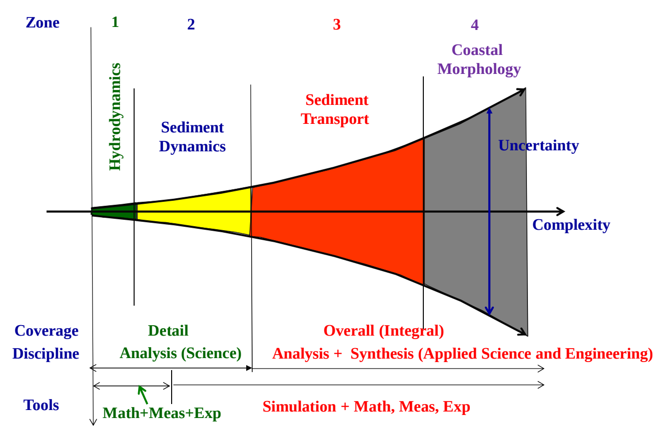

Figure 3 Operational Uncertainty Trumpet for Coastal Dynamics

The basic uncertainty trumpet can easily be extended to zones of further complexity and uncertainty. Figures 2 and 3 only show the physical aspects of coastal processes (i.e., the coastal dynamics). This trumpet can easily be extended into interaction with the physical and social environments (e.g. Zones 5 and 6). These zones deal with how coastal dynamics interact with fish, birds and water quality (environmental) and with fishers, tourists and the economy (social). The uncertainties in those additional zones are greater than for Zone 4 and the research in these extensions becomes multi-disciplinary and trans-disciplinary,

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[2] Research – a definition: The systematic investigation into and study of materials and sources in order to establish facts and reach new conclusions. Ref: Oxford Dictionary.

involving participants of radically different backgrounds (such as various scientists and engineers, stakeholders, government regulators, etc.) gathered around ill-defined problems. The details of research, science and engineering in these zones are beyond the scope of the present paper.

3.2 Research by Academics

A review of the technical literature shows that much published research concerns Zones 1 and 2, the basic, analytical, scientific work. It can also be seen that most of that research is done by academics. There are reasons for this:

- Academic reputation, promotion and funding are all driven by research publications (by individual professors, by research groups and by the university).
- The quality of such publications is judged by two external groups. First is the group that evaluates the quality of potential research from proposals for research funding. They normally follow a set of quality criteria, which are addressed by the research proposals, and grants are based on how well the proposals meet the criteria. Second is the group that evaluates the completed research for publication in reputable journals and proceedings. It has fewer guidelines to determine research quality. Both groups are 'peer groups', consisting of researchers of similar background to the applicants. This means the 'peers' are at least vaguely acquainted with the applicants and their work. Since the 'peers' themselves may be evaluated by the present applicants at some later time, the 'peers' are not entirely independent and the system is flawed.
- Unfortunately, because of obvious administrative and evaluative difficulties, the real criterion for academic reputation and promotion has become simplified to the *number* of publications. Content, such as research quality, complexity of the analysis, potential for innovation, etc. are too difficult to assess fairly in the time available.[3]
- The universities encourage mass production of research because it enhances the university's reputation and because it brings additional funding to augment their budgets.[4,5]
- Academics are, therefore by definition, expected to be actively engaged in research. However, because of the emphasis on number of publications, there is little opportunity for academics to analyze large, poorly defined and complex research projects from Zones 3 and 4 in depth; such research would produce fewer publications per unit of research effort and funding.
- The larger uncertainties for Zones 3 and 4 also make definite research conclusions difficult and therefore, this type of research does not fit efficiently within the science concept of hypothesis-testing-conclusions. As a result, such projects do not score well within the existing peer-adjudicated funding and journal evaluation cultures.

3.3 Research by Practitioners

Industry and government researchers are generally not rewarded for having a large number of publications, but are recognized for the development of innovative solutions to practical problems, and for usable products. This different reward system causes practitioners to concentrate more on research in Zones 3, 4 and beyond. Hence, industry and government do most research in Zones 3 and 4. Unfortunately, these research results are often contained in private, sometimes proprietary reports, because:

- The results are often project-specific and therefore not generally applicable.
- The results often have commercial value that should not be revealed to competitors.

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[3] This is stated quite black-and-white. There are many jurisdictions where judgment by numbers of papers is more nuanced and where other factors are taken into account, if at all possible.

[4] In fact, many universities are primarily interested in large research 'factories'. This means that individual researchers are encouraged to set up large organisations to generate the maximum amount of funding. Unfortunately, this also means that the 'researchers' have little opportunity to actually do research, since they spend much of their time generating funds for their 'research machine'. A newer variant of this is to combine a number of these machines into research institutes, which require even more administration (and less research time for the researchers).

[5] Quote of the day from a university administrator: "Universities are in the business of research and education". A university is just a business? The order of business is first research and then education?

3.4 Need for Close Co-Operation

The different value and reward systems have resulted in a virtual split in coastal dynamics research – a split between analysis and synthesis. This was highlighted, for example, by the theme of the 2011 Coastal Sediments conference, which focused on 'Binding together Theory and Practice'. Kamphuis (2011) discussed this topic further. Figures 2 and 3 do not indicate any such division and there is none!

All this becomes particularly relevant for the research involving synthesis (applied science) and design (engineering). This, mainly Zone 3 and 4 research requires a very close interaction between theory and practice. For best results, the research must combine the research competence of both academics and practitioners; it must join the analytical/theoretical background of the academics with the field experience and the design competence of the practitioners. Thus, there is a need for strong research participation by engineering academics in Zone 3 and 4 research projects, if the quality and understanding of engineering are to advance. The same is true for all applied science research in Zone 3 and 4, that involves synthesis, such as research in oceanography, geomorphology, coastal zone management, etc.

Such strong participation by academics in complex problems in Zones 3 and 4 will not happen if the present rewards system and guidelines within the universities continue. At present, engineering and applied researchers within the universities simply cannot afford to spend the longer time required for research of the complex problems, related to synthesis and design; problems that, in the end, may not even have a clear or single solution. As a result, what is considered 'engineering research' and 'applied science research' in academia is often just 'science research' (analysis), similar to the research carried out by university science departments.

In addition to the above barriers for active participation by academics in research in Zone 3 and 4, this type of research is expensive and can generally not be funded through existing research grants. Hence, much of the research in Zones 3 and 4 must be funded, either from returns resulting from inventions, new and superior methodologies to solve practical problems or from the solutions of actual coastal engineering problems (engineering consulting). This again points to a need for close co-operation between academics and practitioners and perhaps even a need for academics to be both researcher and practitioner to bridge the analysis/synthesis gap.

There are clear indications, however, that the science-based research culture in universities may be changing and that new criteria, such as greater usability and practical application of the research will be considered, in addition to scientific merit. This will be encouraging to some, but dreaded by others as outside interference in 'academic research'. In any case, academic researchers and their universities need to recognize such trends or risk being sidelined. Universities are also becoming aware that students working on hands-on, practical problems generally derive more satisfaction from their work, value their education more and are more likely to find fruitful employment. These changes of focus will certainly open up more opportunities for active, funded participation by academics in research in Zones 3 and 4 and greater co-operation between academia and practice

4. **The Future of Research in Coastal Dynamics**

Much research in coastal dynamics consists of basic research, producing generally applicable results – the research of Zones 1 and 2. The many published and generally available studies form a (large) valuable basis of knowledge. This research was not done necessarily to define or solve pressing, practical problems. Much research simply deepens the general understanding about the processes. This is what is considered 'scientific progress.' This research is indeed necessary and it has been the holy grail of science-based research funding.

It is and has been a privilege and a luxury to be able to concentrate research on the progress of science, but times appear to be changing. With the downturn in the economies of many countries, society and governments will demand that quality criteria such as usability and applicability of research results be seriously considered, in addition to scientific merit. This means that the paper counting by academics and their institutions will automatically produce more practical research, since that is where the more of the funding is directed. This will also automatically lead to closer co-operation between academia and practice.

One additional evaluation criterion that is very likely to be emphasized the near future is *urgency*. To demonstrate this point, consider research on climate change. Such research is desirable and very much *needed*. But learning to prepare communities for climate change impacts and how to make them resilient is *urgent*, since many communities are already affected by climate change. Wonderful Eureka moments must continue to be treasured and rewarded, but guaranteeing safety is urgent.

The introduction of urgency, usability and applicability as basic research criteria will indeed change the research evaluation criteria and the reward system for academic researchers. At present, these researchers are more or less restricted to Zones 1 and 2 but the changes will encourage and enable academics to participate in Zone 3 and 4 research.

Against this background, it is clear that:

- There will be more focus on urgency and usability for research in Zones 1 and 2,
- More research will be encouraged in Zones 3 and 4 (applying and synthesizing results from Zones 1 and 2),
- Closer co-operation between academic researchers and practitioner/researchers from industry and government will take place because academics and practitioners will receive funding that specifically targets such co-operation on Zone 3 and 4 projects.

Some changes are still needed.

- A major change is necessary in focus of the peer adjudication system, instrumental in determining the quality of research and publications. For example, 'Peers' should not only be eminent fellow academic researchers; additional eminent researcher/practitioners from industry and government must be invited to the table[6].
- A clear model must be developed to define 'good research' in Zones 3 and 4.
- Industry must convince itself that in most cases publishing research results is of greater value to their organization than keeping the results proprietary[7].

Finally (and very importantly), it is imperative that academic research never be tied strictly to solutions of practical problems[8]. The practical problem solving should be left to the users, such as governments, private industry and their clients. Academics must never be reduced to just providers of useful input to practical problems. In academia, research should remain independent, innovative and exciting. Above all, it must form a solid education for young professionals, who must be able to function competently throughout all zones of the uncertainty trumpet. At the same time, closer co-operation between academics and practitioners will help to educate young scientists and engineers who can bridge the existing gaps and can function in both academia and practice.

5. **Examples**

We lift two simple examples out of the author's earlier work to demonstrate some of the needs and common difficulties of Zone 3 and 4 research by an academic, but also to show the satisfaction gained from knowing that the results form a bridge between theoretical and practical. It should be remembered that these examples refer to a time when there was considerably less pressure to publish papers and the author had more opportunity for entrepreneurship and inventive financing.

[6] Indeed this is occurring in some jurisdictions.
[7] There are many organizations that now recognize this, viz. open vs. proprietary computer code.
[8] Governments and their research funding directives are beginning to recognize the need for application and usability, but, unfortunately, the focus sometimes swings over from a focus on basic, science-type research to a focus on almost seamlessly joining academic research to solutions of practical problems that benefit the economy of the country. This is understandable in dire economic situations, but it is not good for excellence in university research and particularly not for education of professionals.

5.1 Bottom Friction

Bottom friction under waves is an aggregate representation of the forces and the interactions between the waves and the bottom. Without this, or a similar parameter, it is not possible to describe wave propagation on any aggregate scale (Zones 2 through 4), nor is it possible to describe the interaction between fluid and sediment. A number of researchers were busy with bottom friction research in 1970 and at Queen's University it was decided to perform carefully executed laboratory experiments. The results are reported in Riedel et al. (1972), Riedel and Kamphuis (1973), and Kamphuis (1974, 1975). Figure 4 shows the curves interpolated from the cloud of experimental results and several (semi) empirical expressions were postulated from these data. The research could be classified on the Uncertainty Trumpet as Zone 3

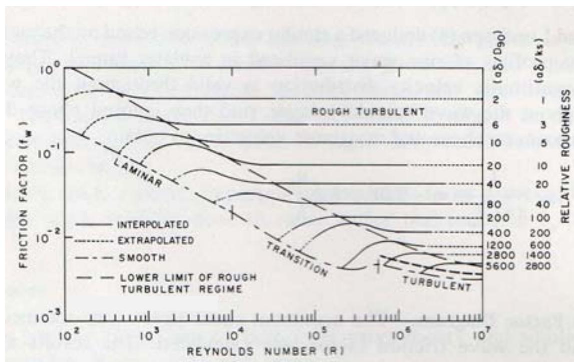

Figure 4 Friction Factor Diagram Ref: Kamphuis (1975)

For this project an oscillating water tunnel was built (Brebner and Riedel - 1973) and an underwater shear plate apparatus was developed (Riedel and Kamphuis – 1973). However, these costly tests only simulated simple sinusoidal wave motion over a flat, fixed-sand bottom. The results were not general and were strictly of limited scope. But the test results were capable of translating the complex processes of wave-bottom interaction into simple manageable aggregated form.

The relationships have since then, however, been universally and successfully applied to practical applications involving irregular waves, mobile bed bottom, etc. and they are regularly used to translate the complex process of wave-bottom interaction into a simple manageable aggregated form for those quite complex physical settings. The relationships form an important and successful bridge between Zone 1 and Zones 2, 3 and 4; between theory and practice. For that reason, the effort and expense were entirely justified on the scale of Figure 2, even though on a more usual academic baseline (Zones 1 and 2) they were difficult to justify.

The three years of work by several researchers resulted in only six papers and one PhD. That would not be considered 'superstar status' under the existing reward system for academics. But the results are and have been very valuable to many users and the tests were indeed landmark tests, because very little has been done to upgrade or expand the dataset and revise the formulae in the 40 years following their publication.

5.2 Bulk Sediment Transport Rate

Kamphuis (1991) published the results of hydraulic model test on alongshore sediment transport rate (ASTR). At the time, there had already been plenty of basic research on fluid flow and sediment dynamics. What was needed was research that could aggregate the basic research, so that scientist and engineers working in Zones 3 and 4 would be able to determine ASTR, a basic ingredient in computations and research on the coastal dynamics of large-scale systems.

The test results shown in Figure 5 were summarized in an expression to compute ASTR.

$$\frac{Q_u}{(\rho_s - \rho) H_{s,b}^3 / T_p} = 7.9x10^{-4} \cdot \left(\frac{H_{s,b}}{L_{o,p}} \right)^{-1.25} \cdot m_b^{0.75} \cdot \left(\frac{H_{s,b}}{D_{50}} \right)^{0.25} \cdot \sin^{0.6}(2\alpha_b) \quad (1)$$

which can be simplified to

$$Q_u = 2.27\, H_{s,b}^2\, T_p^{1.5}\, m_b^{0.75}\, D_{50}^{-0.25} \sin^{0.6}(2\alpha_b) \quad kg/\sec\ (underwater\ mass) \quad (2)$$

For a sand porosity of 0.32, Equations 1 and 2 become

$$Q_v = 7.3 H_{s,b}^2 T_p^{1.5} m_b^{0.75} D_{50}^{-0.25} \sin^{0.6}(2\alpha_b) \quad m^3/hr \quad (3)$$

D_{50} = median particle diameter (mm)
$H_{s,b}$ = significant breaking wave height (m)
$L_{0,p}$ = deep water wave length at peak period (m)
m_b = beach slope in the breaking zone
Q_u = sediment transport in kg/sec underwater mass
Q_v = sediment transport volume in m^3/hr
T_p = peak wave period (sec)
α_b = breaking wave angle (degrees)
ρ = density of water (kg/m^3)
ρ_s = density of the sediment (kg/m^3)

These results required more than a decade of research and involved 3 MSc and 4 PhD studies, an engineer, a technologist, and a large wave basin with ancillary equipment, built specifically for this research project. Once the equipment and methodology were developed, the work became repetitive and boring. Nevertheless, the tests still required several years of constant careful experimentation with special attention to details. This is not exactly the type of research that would be a candidate for the usual type of research funding available to academics. This project, which produced essentially one major research result over 10 years, along with a number of ancillary papers, was funded originally from operating and infrastructure research grants, but they became inadequate and the research funding was augmented from commercial income.

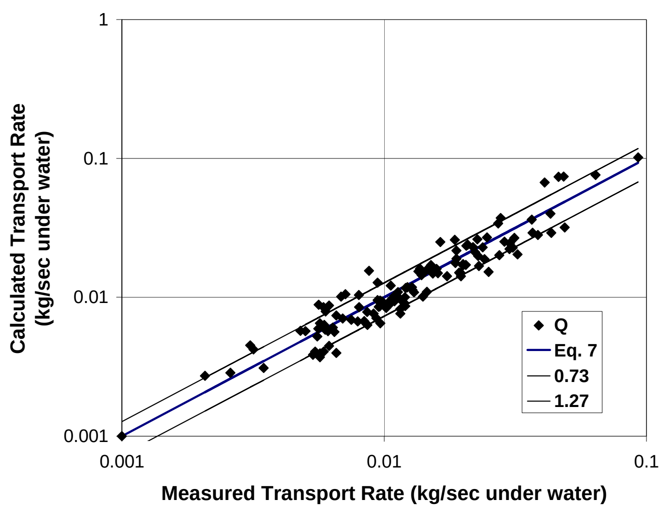

Figure 5 Laboratory Measurements of Alongshore Sediment Transport Rate

The lines in Figure 5 denote the equation of best fit (Equation 1) and the standard deviation (the x0.73 and x1.27 lines contain 68 % of the data). The results are surprisingly good, considering that this research is situated mostly in Zone 3 and 4 of the Uncertainty Trumpet. When the equation derived from the laboratory results was applied to field results, available at the time, the equation provided a very good fit, as shown in Figure 6. This good comparison with existing field results was a strong verification for the relationship derived from the physical model tests. The model relationship (Equation 1) was also successfully applied to laboratory results with larger grain size (gravel) by Van Hijum and Pylarczyk (1982), (marked as VHP in Figure 6), showing the relationship to be entirely robust. The model relationship (Equation 1) was later successfully applied to a large battery of field results by Schoonees and Teron (1994 and 1996). They found that out of a number of ASTR equations, Equation 1 gave the best fit to their field data. Actually, Schoonees and Teron found that the coefficient in Equation 1 needed to be adjusted to fit their data, but Kamphuis (2002) showed that to be incorrect due to their incorrect interpretation of the units of the equation. Equation 1 was shown to be entirely correct as a best fit to their data

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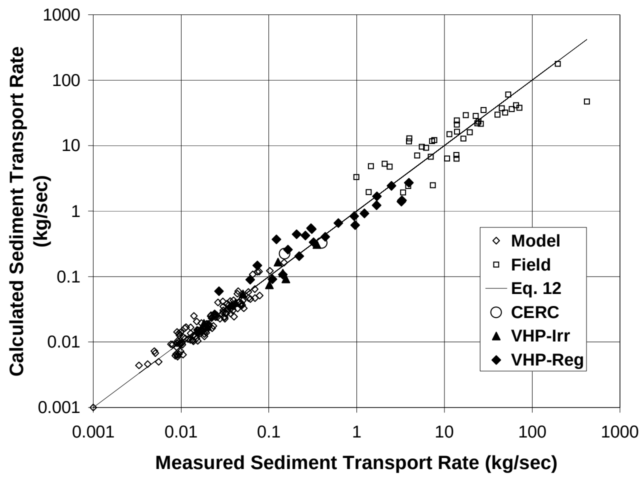

Figure 6 Laboratory and Field Measurements of Alongshore Sediment Transport Rate

Today Equation 1 and its derivatives are regularly used to as a proxy for (prohibitively expensive and time-consuming) field measurement of ASTR. The equation is used as input into research and design projects in Zones 3 and 4. The decade of testing, involving many people, and complicated financing from research grants and monies generated from research and engineering in Zones 3 and 4 was definitely instrumental in bridging the gap between Zones 1 and 2 and Zones 3 and 4. The research effort and expense were entirely justified on the scale of Figure 2.

6. **Conclusions**

The following conclusions may be drawn from this paper:

1) Complexity increases with time and distance scales of a problem and with the number of interacting coastal processes under consideration.
2) Uncertainty increases with complexity.
3) Research is a function of complexity and uncertainty of the processes being investigated.
4) Academics must be active in research, since academic reputation is based primarily on the number of published papers and universities depend heavily on the additional income generated by research funding. Because of the pressure to publish, academics tend to focus their research on the more theoretical, less complex processes to produce a maximum number of publications.
5) Industry and government researchers respond to a different reward system, based on innovative solutions to practical problems and production of directly usable results. Therefore, their research tends to focus on the more complex processes.

6) This difference in research focus has resulted in a cultural divide between theory and practice, which must be bridged if the overall understanding of coastal dynamics is to be increased. That requires a radical cultural change in management of research funding and a re-alignment of reward systems, so that academics are encouraged to participate in research of the more complex issues, at the same time bringing about greater co-operation between researchers from industry, government and academics.
7) There is a trend to introduce basic research quality criteria in addition to scientific merit. These are usability, applicability, and possibly urgency. These criteria are certain to bring about a change of focus in academic research, moving it toward more practical application and co-operation with practitioners.
8) Academic research must never be strictly tied to solution of specific practical problems. In academia, research must remain independent, innovative and exciting and form a solid education for young professionals to function in all environments of academia and practice.

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8. **Acknowledgments**

The author gratefully acknowledges the use of excellent research facilities and the interaction with gifted students at Queen's University Civil Engineering.