Hydroinformatik - SoSe 2025
UM-BHW-414-F: Hydrologische Modellierung

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Zeitplan: Hydroinformatik I+II

Sommersemester 2025

Stand: 08.05.2025

Nr.	KW	Datum	ID	Thema
01	15	11.04.2025	UW-BHW-414-A	Einführung, Werkzeuge#1, Hello World
03	17	25.04.2025	UW-BHW-414-B	Umweltinformatik, Werkzeuge#2 (git), Datentypen
05	18	02.05.2025	UW-BHW-414-C	Selbststudium
07	19	09.05.2025	UW-BHW-414-D	Objekt-Orientierte Programmierung: C++, Klassen
09	20	16.05.2025	UW-BHW-414-E	Python
11	21	23.05.2025	UW-BHW-414-F	Modellierung, Digitalisierung, Wasser 4.0
11	22	30.05.2025	UW-BHW-414-G	KI, Maschinelles Lernen, Neuronale Netzwerke
13	23	06.06.2025	UW-BHW-414-H	Kontinuumsmechanik, Hydromechanik
05	18	13.06.2025		Vorlesungsfreie Woche
15	25	20.06.2025	UW-BHW-414-I	Differentialgleichungen, Näherungsverfahren
17	26	27.06.2025	UW-BHW-414-J	Finite-Differenzen, explizite Verfahren
19	27	04.07.2025	UW-BHW-414-K	Finite-Differenzen, implizite Verfahren
21	28	11.07.2025	UW-BHW-414-L	Gerinnehydraulik, Grundwasserhydraulik
23	29	18.07.2025	UW-BHW-414-M	Zusammenfassung, Klausurvorbereitung

Fahrplan für heute ...

0. Rückblick letzte Veranstaltung: Python

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1. Modell-Begriff
2. Hydro-Systeme
3. Hydro-System Modelle
4. Prozessbasierte Hydro-System Modelle
5. "Surrogate" Modelle
6. (professional) Work Flows ...

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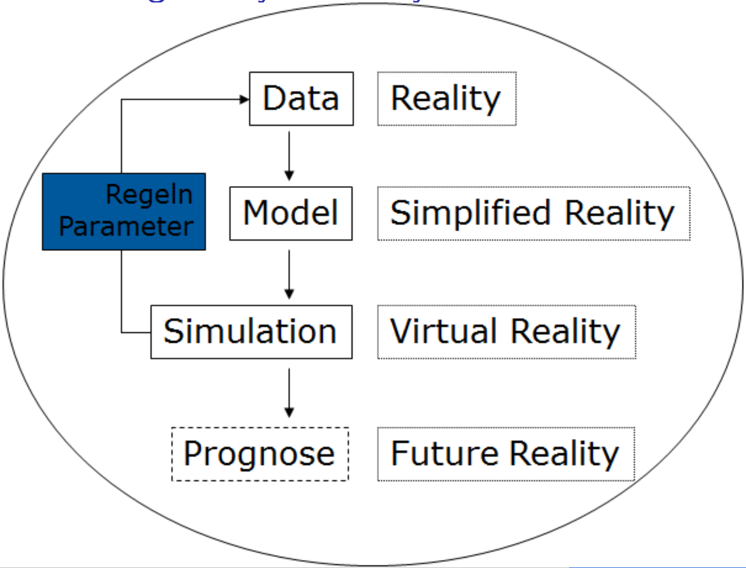
7. Ausblick auf die nächste Veranstaltung: KI

Modell-Begriff (Theorie)

Modell-Begriff: Systemanalyse



↪ Kalibrierung ⟶

Validierung ⟶

Verfizierung (A & B) ⟵

Modell-Begriff: Publikation: Görke et al. (2015)

VI International Conference on Computational Methods for Coupled Problems in Science and Engineering
COUPLED PROBLEMS 2015
B. Schrefler, E. Oñate and M. Papadrakakis(Eds)

ON THE TERM AND CONCEPTS OF NUMERICAL MODEL VALIDATION IN GEOSCIENTIFIC APPLICATIONS

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Key words: Coupled Problems, Model Development, Numerical Methods, Model Confirmation, Inverse Problems

Abstract. Modeling and numerical simulation of the coupled physical and chemical processes observed in the subsurface are the only options for long-term analyses of complex geological systems. This contribution discusses some more general aspects of the (dynamic) process modeling for geoscientific applications including reflections about the slightly different understanding of the terms *model* and *model validation* in different scientific communities, and about the term and methods of *model calibration* in the geoscientific context. Starting from the analysis of observations of a certain part of the perceived reality, the process of model development comprises the establishment of the physical model characterizing relevant processes in a problem-oriented manner, and subsequently the mathematical and numerical models. Considering the steps of idealization and approximation in the course of model development, Oreskes et al. [1] state that process and numerical models can neither be verified nor validated in general. Rather the adequacy of models with specific assumptions and parameterizations made during model set-up can be confirmed. If the adequacy of process models with observations can be confirmed using lab as well as field tests and process monitoring, the adequacy of numerical models can be confirmed using numerical benchmarking and code comparison. Model parameters are intrinsic elements of process and numerical models, in particular constitutive parameters. As they are often not directly measurable, they have to be established by solving inverse problems based on an optimal numerical adaptation of observation results. In addition, numerical uncertainty analyses should be an obligatory part of numerical studies for critical real world applications.

Link

1 INTRODUCTION

Modeling and numerical simulation of the coupled physical and chemical processes observed in the subsurface are the only options for long-term analyses of complex geological systems. The numerical simulation of geotechnological processes (*dynamic modeling*) requires the existence of models that describe the considered problems as adequately as possible. Within this context, it has to be considered that models represent approximations and idealizations of the considered part of the perceived reality, and will map the real world by approximation. During the process of model development, certain relevant aspects will be covered sufficiently accurate, whereas other details, which can be considered as irrelevant for the specific problem definition, can be neglected. In this approximate sense, models are qualified to enable predictions of the behavior of real-world processes, which are not (yet) open for efficient empirical measuring procedures due to exceptional long time scales to be considered (e.g., within the context of geological waste deposition) or due to the general difficult access to local *in situ* measurements in the subsurface. However, absolute exact predictions can never be expected based on process modeling. The model quality, i.e., the degree of conformance of models with the part of the perceived reality they describe, and thus the reliability of model predictions, depends on many factors. Within this context, the quality as well as the spatial and time density of measured data characterizing the observation area plays a crucial role. These data are necessary for parameterization (i.e., calibration; parameter identification; inverse modeling) and confirmation of the developed models.

2 MODELS WITHIN A GEOSCIENTIFIC CONTEXT – AN ATTEMPT OF DISAMBIGUATION

Discussing about *models* in a geoscientifc context, different scientific communities (e.g., geologists; geophysicists; experts in continuum mechanics; engineers) sometimes use this term based on slightly different associations. Thus, in the following we attempt to provide clear definitions of the term *model*:

- **Spatial and/or structural models** usually will be summarized using the term *(static) reservoir model*, and comprise all empirically ascertainable information regarding geometry, geological structure, basic material characteristics (e.g., porosity, intrinsic permeability, thermal and mechanical parameters), and reservoir conditions (e.g., pressure, temperature) of the considered area.
- **Process models** represent *mathematical models* based on physically founded assumptions about coupled physical, geochemical, geoelectrical, and (micro-)biological processes observed in real-world applications. Basically, process models include balance laws and constitutive relations. More detailed reflections regarding process modeling will be discussed in Sec. 3 of this contribution.

Modell-Begriff

Definition

"Modeling and numerical simulation of the coupled physical and chemical processes observed in the subsurface are the only options for **long-term analyses** of complex geological systems. The numerical simulation of geotechnological processes (dynamic modeling) requires the existence of **models that describe the considered problems as adequately as possible**. Within this context, it has to be considered that models represent **approximations and idealizations** of the considered part of the perceived reality, and will map the real world by approximation. During the process of model development, certain relevant aspects will be covered sufficiently accurate, whereas other details, which can be considered as irrelevant for the specific problem definition, can be neglected. In this approximate sense,

Görke, U.-J., Nagel, T., Kolditz, O., (2015): On the term and concepts of numerical model validation in geoscientific applications In: Schrefler, B., Oñate, E., Papadrakakis, M., (eds.) Proceedings of the 6th International Conference on Computational Methods for Coupled Problems in Science and Engineering – COUPLED PROBLEMS 2015, CIMNE, 18 - 20 May 2015, San Servolo, Venice, Italy

Modell-Begriff

Definition

... models are qualified to enable predictions of the **behavior of real-world processes**, which are not (yet) open for efficient empirical measuring procedures due to exceptional long time scales to be considered (e.g., within the context of geological waste deposition) or due to the general **difficult access to local in-situ measurements** in the subsurface. However, absolute exact predictions can never be expected based on process modeling. The **model quality**, i.e., the degree of conformance of models with the part of the perceived reality they describe, and thus the reliability of model predictions, depends on many factors. Within this context, the quality as well as the spatial and time density of measured data characterizing the observation area plays a crucial role. These data are necessary for **parameterization** (i.e., calibration; parameter identification; inverse modeling) and confirmation of the developed models."

Modell-Begriff

Definition: wichtige Punkte

- Approximation und Idealisierung (Näherung der Realität)
- Systembeschreibung (so realistisch wie möglich, wichtigste Prozesse)
- Vorhersagen (in Raum und Zeit)
- Fehlen von Daten für die Modell-Parameterisierung (zu teuer, nicht zugänglich)
- Modell-Qualität: Bewerten, wie gut ist ein Modell (quantitativ)

Modell-Abstraktion

Geo-Systeme $\Rightarrow$ Hydro-Systeme

Modell-Begriff

Klassifikation

Discussing about models in a geoscientific context, different scientific communities (e.g., geologists; geophysicists; experts in continuum mechanics; engineers) sometimes use this term based on slightly different associations. Thus, in the following we attempt to provide clear definitions of the term model:

- **Spatial and/or structural models** usually will be summarized using the term (static) reservoir model, and comprise all empirically ascertainable information regarding geometry, geological structure, basic material characteristics (e.g., porosity, intrinsic permeability, thermal and mechanical parameters), and reservoir conditions (e.g., pressure, temperature) of the considered area.
- **Process models** represent mathematical models based on physically founded assumptions about coupled physical, geochemical, geoelectrical, and (micro-)biological processes observed in real-world applications. Basically, process models include balance laws and constitutive relations. More detailed reflections regarding process modeling will be discussed in Sec. 3 of this contribution.

Modell-Begriff

Klassifikation

- **Numerical models:** The field equations based on balance laws including relevant constitutive relations can be solved analytically just in exceptional cases. Corresponding specific problems frequently will be defined in terms of benchmarks for model and software confirmation. Usually, the solution of field equations describing a real-world problem requires the use of numerical methods. For that, the local formulation of balance laws in terms of differential equations has to be transformed into a global integral formulation. In general, the resulting system of equations is a nonlinear one and contains time derivatives of the primary variables to be calculated. As numerical methods do not provide spatially and temporally continuous solutions, but rather solutions in discrete points of the given solution space, the system of field equations including constitutive relations has to be discretized in space and time within the context of incremental-iterative approximation procedures. In addition, nonlinear systems have to be linearized. The resulting so-called initial-boundary value problem can be solved numerically in discrete locations at discrete points of time. As spatial discretization approaches, the methods of finite differences (FDM), finite volumes (FVM), and finite elements (FEM) are widely excepted means of choice.

Modell-Begriff

Klassifikation: wichtige Punkte

- Prozess-Modelle: Abbildung der wichtigsten Prozesse (Physik, Chemie, Biologie)
- Modell-Gebiet: geometrisches Strukturmodell (numerische Diskretisierung, Rechengitter)
- Analytische und numerische Modelle: Näherungsmethoden, Numerische Methoden (z.B. finite Differenzenverfahren, finite Elemente-Methode)

Modell-Begriff

Process Modeling: Modellbildung

The process modeling of physical, geochemical, and (micro-)biological processes in the subsurface is based on mathematical theories enabling the description of spatially and temporally evolving processes of the perceived reality in terms of differential equations or systems of differential equations. Developing the relevant mathematical apparatus, we make use of physically, chemically, and biologically founded assumptions.

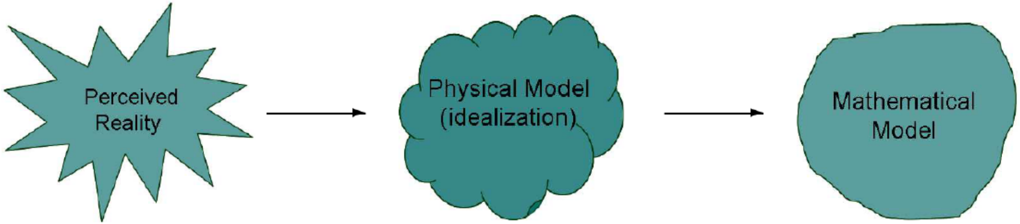


Figure: Model generation

Modell-Begriff

Modell-Qualität: Valisierung und Verifizierung

The procedure of the development of process models illustrated in Sec. 3 shows that models are always idealizations and approximations of a considered part of the perceived reality reflecting specific assumptions and parameterizations made for the model set-up. In order to assure the usability of a process model and the corresponding numerical model, it has to be shown that it adequately reflects real-world processes. In the literature, this process is called **model validation** or even **model verification** – but are these terms justified in their absolute, literal meaning?

Modell-Begriff

Model Confirmation

- **Model validation** ". . . does not necessarily denote an establishment of truth. . . Rather, it denotes the establishment of legitimacy. . . " and ". . . a model that does not contain known or detectable flaws and is internally consistent can be said to be valid."
- **Model verification** ". . . means an assertion or establishment of truth." and "To say that a model is verified is to say that its truth has been demonstrated, which implies its reliability as a basis for decision-making."

Source: Oreskes, N., Shrader-Frechette, K. and Belitz, K. Verification, Validation, and Confirmation of Numerical Models in the Earth Sciences. Science (1994) 263:641–646.

Modell-Begriff

Model calibration

Model parameters, in particular constitutive parameters, are constituent, intrinsic elements of process and numerical models. Parameterized models are used for simulations in order to analyze and/or predict the evolution of various processes in real-world applications, thus, solving a direct problem (cf. Fig. 4).

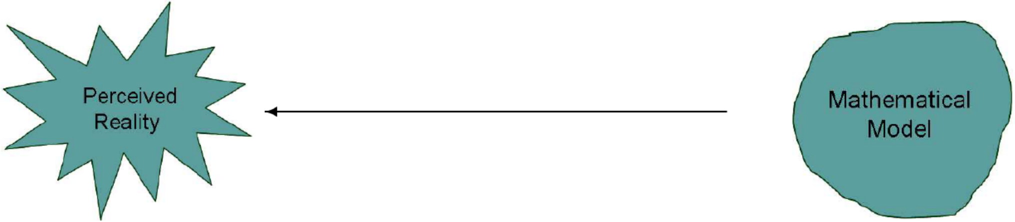


Figure: Direct modeling: simulation of real-world problems using parameterized process and numerical models

Modell-Begriff

Model optimization

As model parameters are often not directly measurable, their identification is based on the analysis of their effects onto measurable field variables. This process of model calibration (i.e., model parameterization) requires the solution of an inverse problem based on an optimal numerical adaptation of observation results (cf. Fig. 5).

Figure: Inverse modeling: optimal numerical adaptation of observations from lab and field experiments, and from field exploration

Modell-Begriff

Objective function

A model function will be defined, which characterizes an arbitrary field variable y depending on a vector of variables $\boldsymbol{x}$ as well as on a set (vector) of model parameters $\boldsymbol{c}$. $\hat{y}_i$ are measured data for comparison and evaluation of the model quality.

$$y = y(\boldsymbol{x}, \boldsymbol{c}) \tag{1}$$

Norms:

$$\frac{1}{2} \sum_{i=1}^{n} = [\hat{y}_i^2 - y^2(\boldsymbol{x}, \boldsymbol{c})] = \boldsymbol{r}(\boldsymbol{c}) \rightarrow \min \tag{2}$$

Residuals:

$$\boldsymbol{r}(\boldsymbol{c}) = \{r_i(\boldsymbol{c})\} \quad \text{with} \quad r_i(\boldsymbol{c}) = \hat{y}_i - y(\boldsymbol{x}_i, \boldsymbol{c}) \tag{3}$$

Modell-Begriff

Objective function

Objective function

$$\Phi(\boldsymbol{c}) = \frac{1}{2}\boldsymbol{r}^T(\boldsymbol{c})r(\boldsymbol{c}) = \frac{1}{2}\sum_{i=1}^{n} = \hat{r}_i^2(\boldsymbol{c}) \rightarrow \min \tag{4}$$

Optimality criterion

$$\nabla\Phi(\boldsymbol{c}^*) = 0 \tag{5}$$

Normal equation

$$\boldsymbol{J}^T\boldsymbol{J}\boldsymbol{c}^* = \boldsymbol{J}^T\boldsymbol{r} \tag{6}$$

Jacobian matrix

$$\boldsymbol{J} \tag{7}$$

Modell-Begriff

Conclusions

Following aspects are important to reliable process simulations:

- Definition of the **processes and subprocesses** that are relevant for the specific problem to be solved in order to establish a system of field equations, which is complex enough to cover the relevant system behavior but simple enough to ensure an efficient and stable solution process.
- Formulation of problem-dependent specific expressions of the **balance laws and the constitutive relations** according to the latest state of research.
- Model confirmation using standardized **benchmarks and code comparison**.
- Extensive provision of **data** from lab and field tests for an improved process understanding and for the model calibration.
- If measured data are not available for all local points of the spatially discretized observation area (this is the usual case for geoscientific real-world applications), a stochastically based parameter space has to be determined based on a statistically sufficient number of different numerical realizations.
- An **uncertainty analysis** is advised based on this parameter space, and results of the process simulation will be provided with certain likelihood.

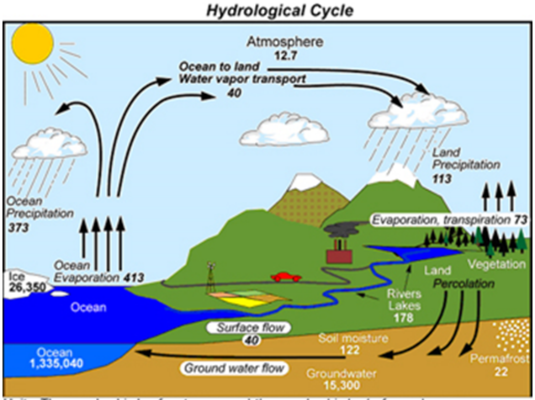
Hydro-System Modelle

Hydrosysteme

Totes Meer (Dead Sea) - Arid

Elbe - Humid

Wasserkreislauf



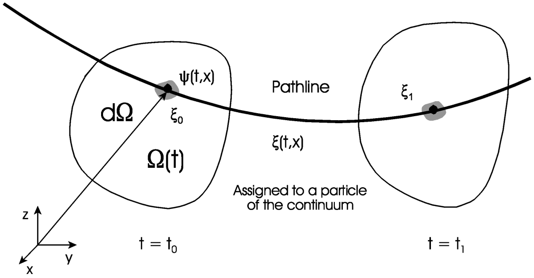
Hydro-System Modelle

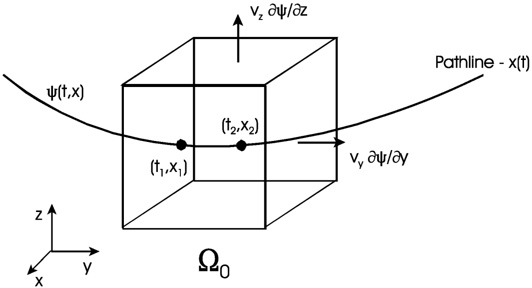
- Prozessbasierte Modelle
- Datenbasierte Modelle (Vorlesung Jakob Zscheischler)

Prozessbasierte Modelle

Prozessbasierte Modelle

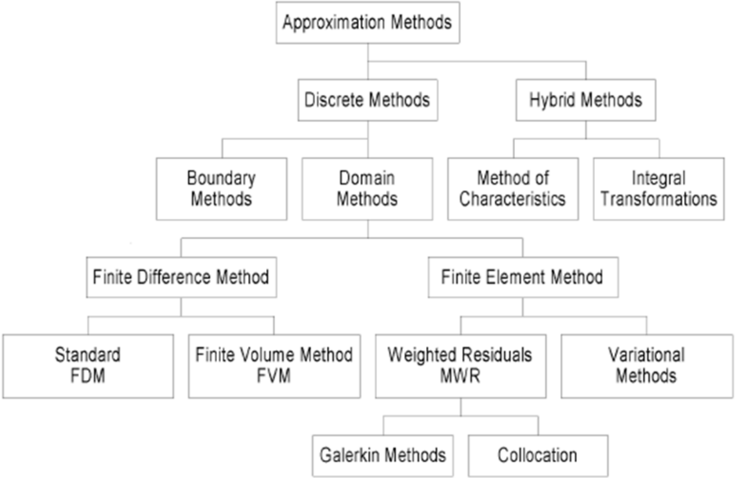
Grundprinzipien (Vorlesungen im zweiten Teil des Semesters)





Prozessbasierte Modelle

Näherungsmethoden (Vorlesungen im zweiten Teil des Semesters)



Prozessbasierte Modelle

Beispiele (Vorlesungen im zweiten Teil des Semesters)

Finite Differenzen Modell (MODFLOW)

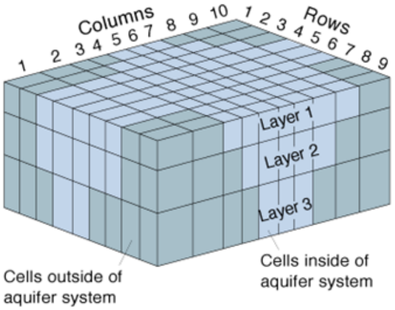
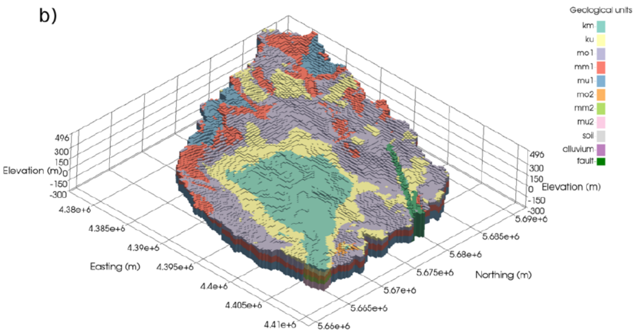


Figure 2. Example of model grid for simulating three-dimensional ground-water flow.

Finite Elemente Modell (OpenGeoSys)



Modell für das Thüringer Becken

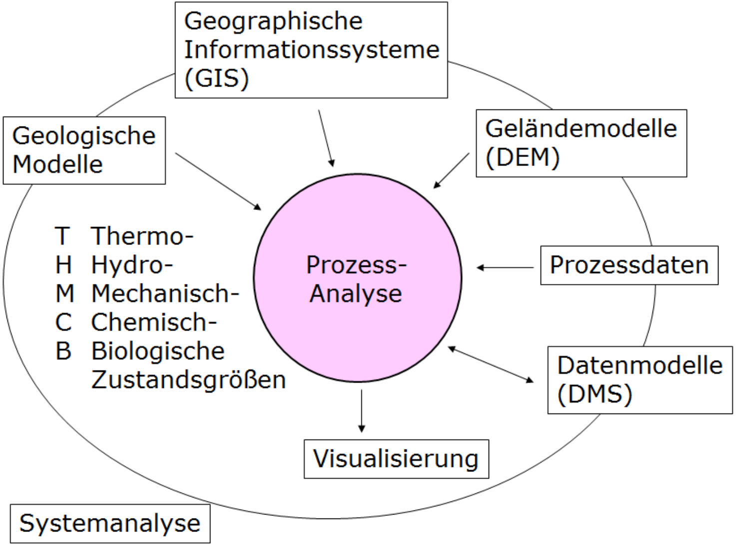
Datenbasierte Modelle

Nächste Vorlesung

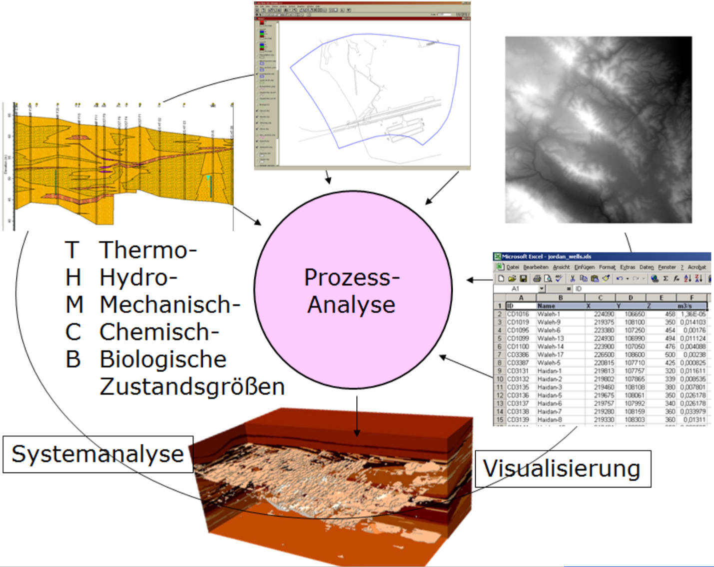
- Stochastische Modelle
- Netzwerke (Neuronale, Bayes'sche Netzwerke, ...)
- Machine Learning (KI)
- ...

Workflows ...

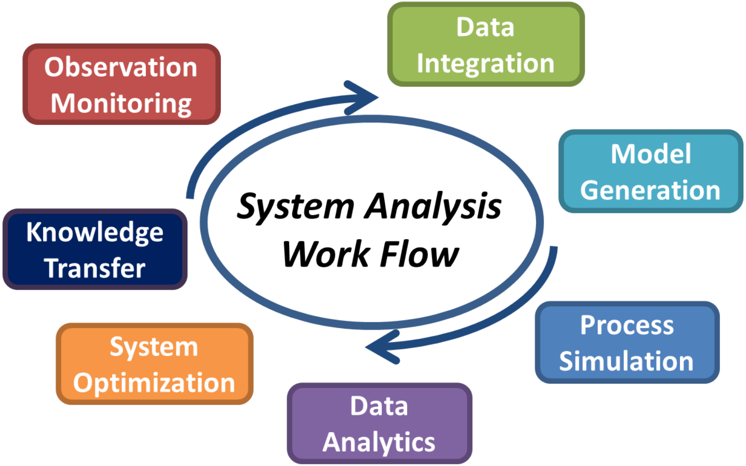
Workflows


Geographische Informationssysteme (GIS)
Geologische Modelle
Geländemodelle (DEM)
T Thermo-
H Hydro-
M Mechanisch-
C Chemisch-
B Biologische
Zustandsgrößen
Prozess-Analyse
Prozessdaten
Datenmodelle (DMS)
Visualisierung
Systemanalyse

Workflows


T Thermo-
H Hydro-
M Mechanisch-
C Chemisch-
B Biologische
Zustandsgrößen
Prozess-
Analyse
Systemanalyse
Visualisierung

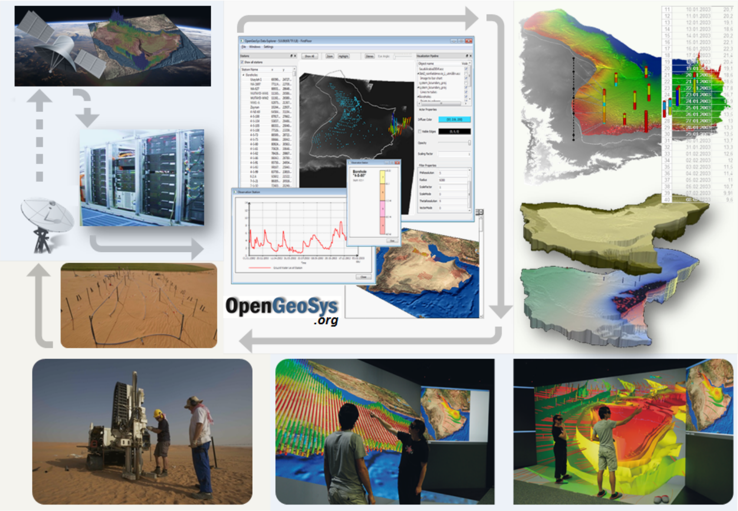
Workflows: Generic Concept



Object Orientation

OpenGeoSys workflows

Workflows: Hydrosystems



Quelle: Kalbacher et al. (2012)

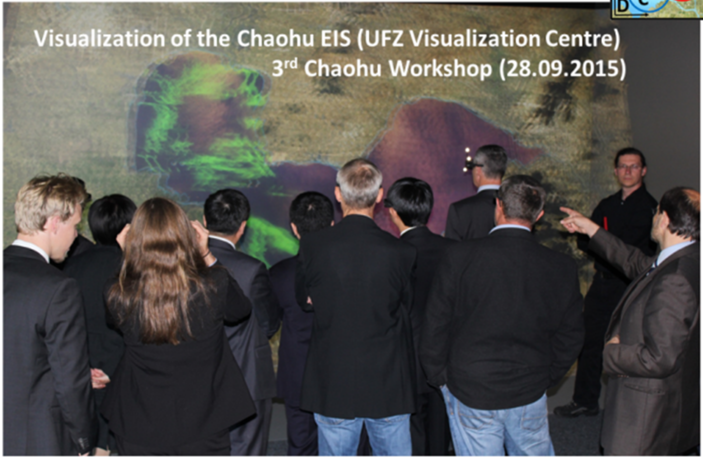
Visualisierung: Lars Bilke und Karsten Rink

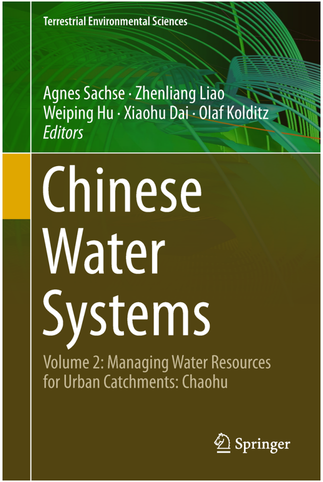
>> Videolink

CAWR Project: "Urban Catchments"

Visualisierung: Karsten Rink

D. Environmental Information System

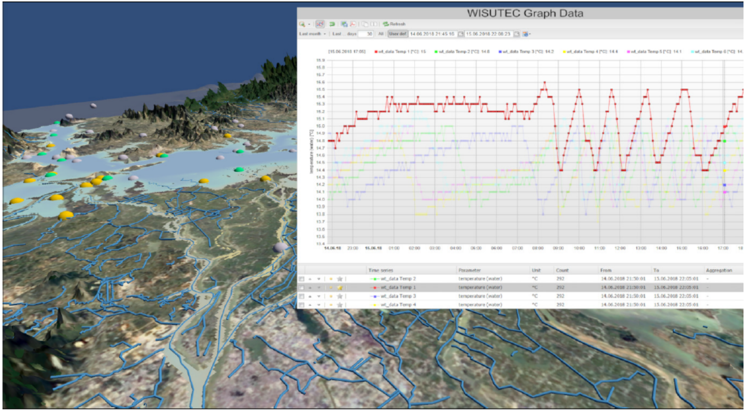


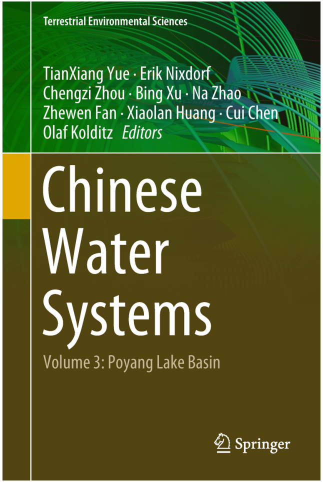


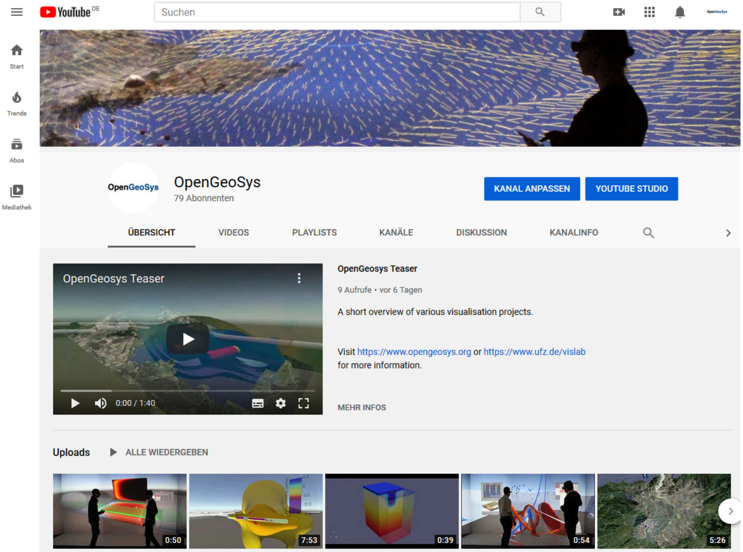
DFG#NSFC Project: "Poyang Lake"

Visualisierung: Karsten Rink

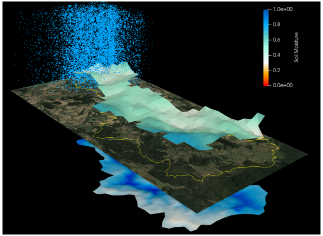
>> Videolink

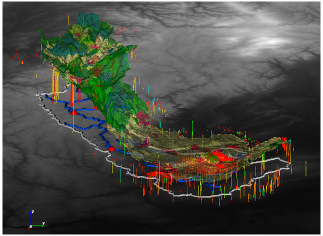






https://www.youtube.com/user/OpenGeoSys





Hydroinformatik - SoSe 2025
UW-BHW-414-F2: BigData, Wasser 4.0

Olaf Kolditz

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Dresden, 23.05.2025

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https://bildungsportal.sachsen.de/opal/auth/RepositoryEntry/32518209537?10

Big Data

Fahrplan für heute ...

0. Rückblick letzte Veranstaltung: Modellierung

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1. Definition
2. Forschungsbedarf
3. Beispiele aus der Umwelt
4. Wasser 4.0

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5. Ausblick auf die nächste Veranstaltung: KI

Big Data

Definition(en)

Big Data

Definition: Wikipedia

Der aus dem englischen Sprachraum stammende Begriff Big Data (von englisch big ‚groß' und data ‚Daten') bezeichnet Datenmengen, welche

- zu groß,
- zu komplex,
- zu schnelllebig oder
- zu schwach strukturiert

sind, um sie mit manuellen und herkömmlichen Methoden der Datenverarbeitung auszuwerten. Im deutschsprachigen Raum ist der traditionellere Begriff Massendaten gebräuchlich. „Big Data" wird häufig als Sammelbegriff für digitale Technologien verwendet, die in technischer Hinsicht für eine neue Ära digitaler Kommunikation und Verarbeitung und in sozialer Hinsicht für einen gesellschaftlichen Umbruch verantwortlich gemacht werden. Er steht dabei grundsätzlich für große digitale Datenmengen, aber auch für deren Analyse, Nutzung, Sammlung, Verwertung und Vermarktung.

Source: https://de.wikipedia.org/wiki/Big_Data

Big Data

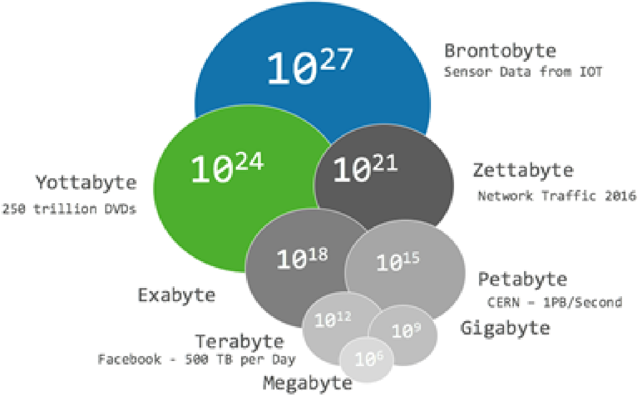
Definition: Wikipedia

In der Definition von Big Data bezieht sich das „Big“ auf die drei Dimensionen volume (Umfang, Datenvolumen), velocity (Geschwindigkeit, mit der die Datenmengen generiert und transferiert werden) sowie variety (Bandbreite der Datentypen und -quellen). Erweitert wird diese Definition um die zwei V's value und validity, welche für einen unternehmerischen Mehrwert und die Sicherstellung der Datenqualität stehen. Der Begriff „Big Data“ unterliegt als Schlagwort einem kontinuierlichen Wandel; so wird mit ihm ergänzend auch oft der Komplex der Technologien beschrieben, die zum Sammeln und Auswerten dieser Datenmengen verwendet werden. Die gesammelten Daten können dabei aus verschiedensten Quellen stammen (Auswahl):

Source: https://de.wikipedia.org/wiki/Big_Data

Big Data

Definition



Source: `http://api.ning.com`

Big Data

Definition

Big Data (Definition)

- **V**olume (Datenmenge -> Fernerkundung)
- **V**ariety (Heterogenität -> multivariante Daten ...)
- **V**elocity (Geschwindigkeit -> in-situ Visualisierung ...)
- **V**eracity (Wahrheitsgehalt -> Unsicherheiten ...)
- **V**isualization (in-situ, VISLAB 2.0)

Data Management

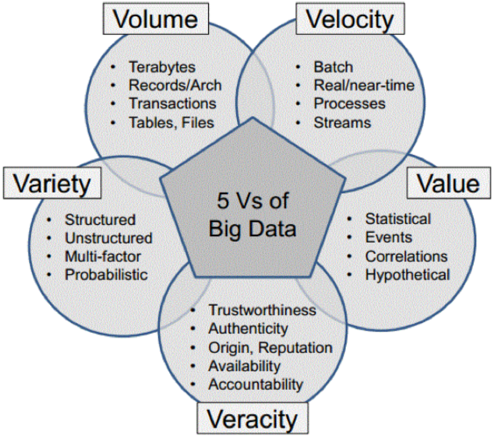
Q

Visual Analytics

- **Value**

Big Data

Definition



Source www.linkedin.com/pulse/big-data-vs-semantic-web-wael-almadhoun-pmp-ocp

Big Data

Forschung

Big Data

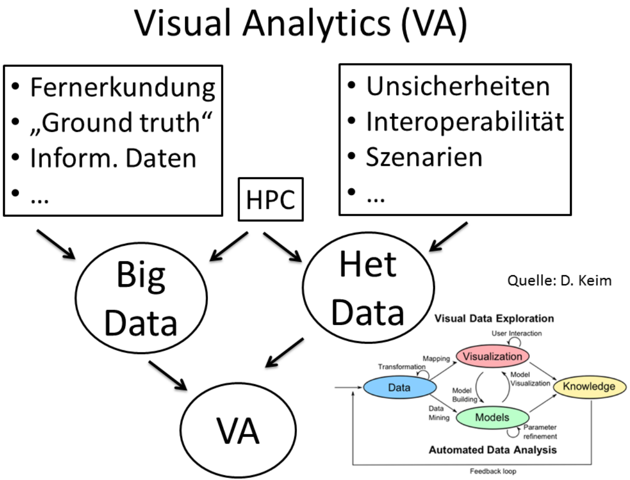
Forschung

Forschungsbedarf (aus Sicht der Visualisierung)

- Challenge: **Big Data**, z.B. aus Fernerkundung (Hyperspektraldaten), hochaufgelöste Geophysik und Simulationsergebnisse (High-Performance-Computing)
- Methodik: **Visual Analytics** (neue Erkenntnisse gewinnen aus großen und heterogenen Datenmengen)
- Methodik: Interaktive **Workflows**: automatisierte Datenanalyse, Qualitätsmanagement (Validierung), visuelle Datenexploration, Mustererkennung, in-situ Visualisierung
- Sichtbarkeit: EUROVIS Workshop „EnvirVis“ (EES TI)

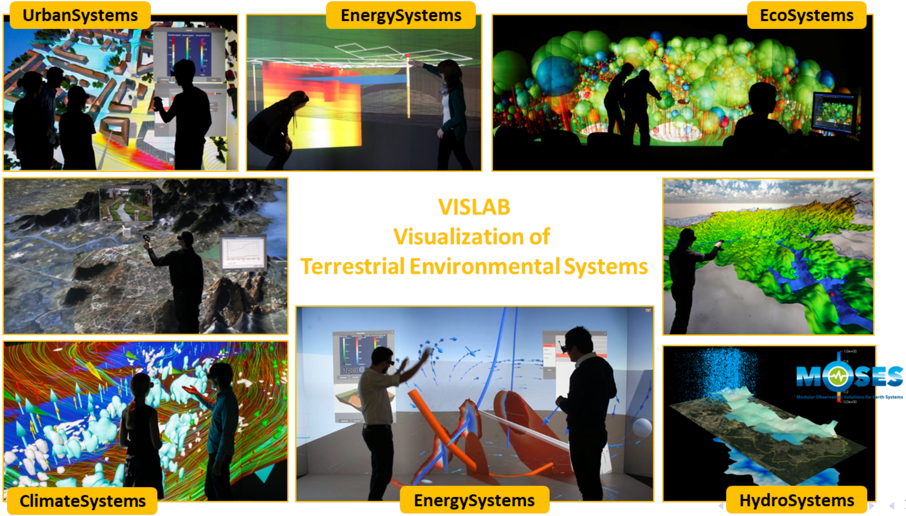
Big Data

Forschung



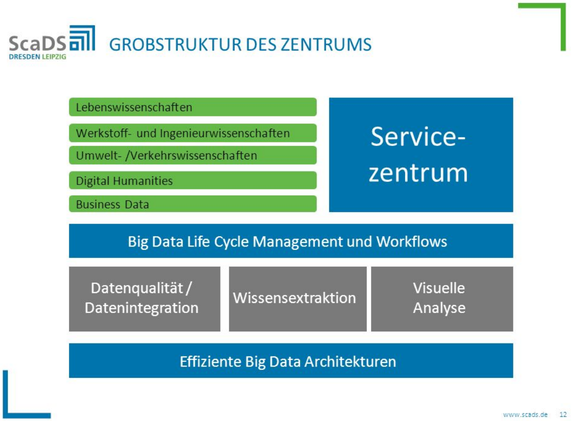
Big Data

Forschung: Umweltinformationssysteme (www.ufz.de/vislab)



Big Data

Forschung: ScaDS >> ScaDS.AI



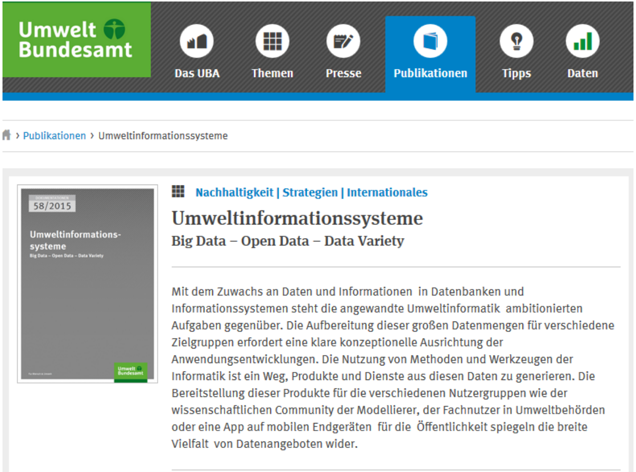
Source `www.scads.de`

Big Data

Beispiele aus der Umwelt

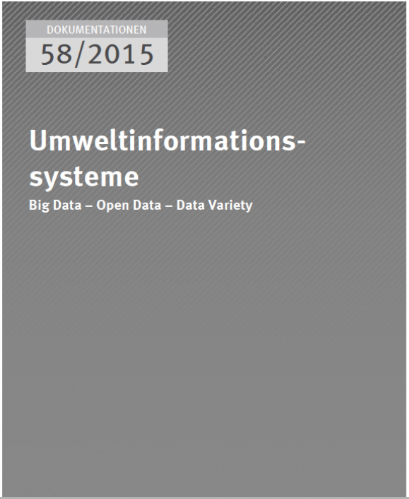
Big Data

Behörden



Source: UBA

Big Data
Behörden



Themen (Workshop 2015)

- Umwelt-Sensordaten (SOS Web Services)
- Metadaten
- Geodateninfrastrukturen
- Cloud Computing für die Kalibrierung von Hochwassersimulationen
- Geovisualiserung
- Crowdsourcing
- neuer Eintrag
- ...

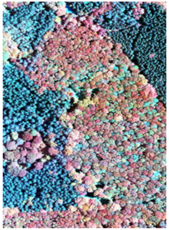
Big Data

Forschung: Fernerkundung

Erfassung und Auswertung von Hyperspektraldaten

Früherkennung von Waldschäden

- Vorbereitung schneller, sicherer und umweltschonender Maßnahmen zur Früherkennung und Prävention von Kalamitätsfällen im Forstbereich
- Hochdimensionale funktionale und hochaufgelöste 3D-Rasterdaten aus Befliegungen von Waldgebieten
- Eine Vielzahl von Einflussfaktoren überlagert das hochdimensionale Signal
- Kalibrierung der Spektraldaten durch Methoden des maschinellen Lernens
- Algorithmen zur Separierung einzelner Baumkronen und Ableitung deren hyperspektraler Signatur
- Aussagen zur Baumart, Vitalität sowie zu biotischen und abiotischen Stressfaktoren



Fraunhofer IFF

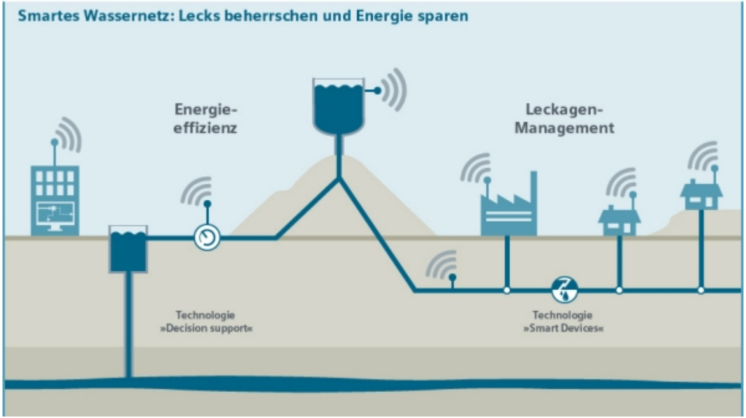
1

Fraunhofer BIG DATA

Source: Fraunhofer BIG DATA

Big Data

Industrie: Von Big to Smart Data



Source: Siemens
https://www.siemens.com/innovation/de/home/pictures-of-the-future/digitalisierung-und-software/von-big-data-zu-smart-data-projekt-icewater.html

Wasser 4.0

Big Data

Industrie 4.0

Industrie 4.0 ist ein Begriff, der auf die Forschungsunion der deutschen Bundesregierung und ein gleichnamiges Projekt in der Hightech-Strategie der Bundesregierung zurückgeht; zudem bezeichnet er ebenfalls eine Forschungsplattform.[1][2][3] Die industrielle Produktion soll mit moderner Informations- und Kommunikationstechnik verzahnt werden.[4] Technische Grundlage hierfür sind intelligente und digital vernetzte Systeme. Mit ihrer Hilfe soll eine weitestgehend selbstorganisierte Produktion möglich werden: Menschen, Maschinen, Anlagen, Logistik und Produkte kommunizieren und kooperieren in der Industrie 4.0 direkt miteinander.[4] Durch die Vernetzung soll es möglich werden, nicht mehr nur einen Produktionsschritt, sondern eine ganze Wertschöpfungskette zu optimieren. Das Netz soll zudem alle Phasen des Lebenszyklus des Produktes einschließen – von der Idee eines Produkts über die Entwicklung, Fertigung, Nutzung und Wartung bis hin zum Recycling.[4]

Source: Wikipedia

Big Data

Industrie 4.0

Mit der Bezeichnung "Industrie 4.0" soll das Ziel zum Ausdruck gebracht werden, eine vierte industrielle Revolution einzuleiten.

1. Die erste industrielle Revolution bestand in der Mechanisierung mit Wasser- und Dampfkraft, darauf folgte
2. die zweite industrielle Revolution: Massenfertigung mit Hilfe von Fließbändern und elektrischer Energie,
3. daran anschließend die dritte industrielle Revolution oder digitale Revolution mit Einsatz von Elektronik und IT (v. a. die speicherprogrammierbare Steuerung) zur Automatisierung der Produktion.

Mit dem Ausdruck „4.0“ wird Bezug genommen auf die bei Software-Produkten übliche Versionsbezeichnung, die bei größeren Änderungen von einer neuen Version spricht, die erste Ziffer der Versionsnummer um Eins erhöht und gleichzeitig die zweite Ziffer auf Null zurücksetzt.

Source: Wikipedia

Big Data

Wasser 4.0

GWP-Arbeitskreis Wasser 4.0

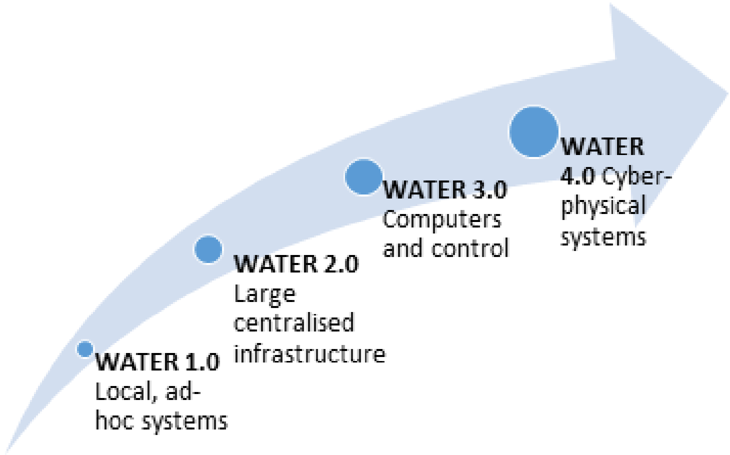
Big Data

Wasser 4.0

Wasser 4.0 stellt die Digitalisierung und Automatisierung in den Mittelpunkt einer Strategie für eine ressourceneffiziente, flexible und wettbewerbsfähige Wasserwirtschaft.

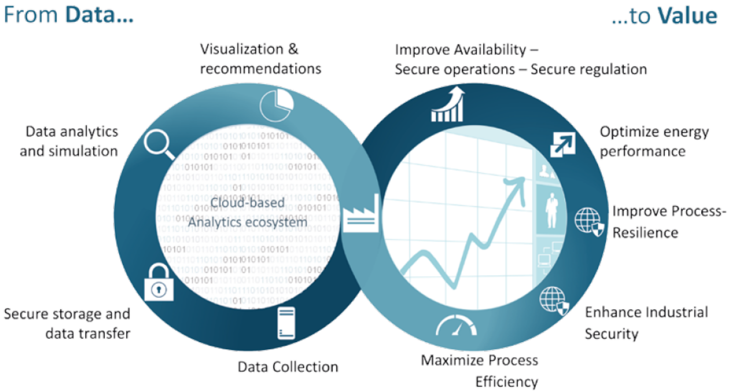
Source: German Water Partnership
http://www.germanwaterpartnership.de/de/arbeitskreise/wasser-40/index.htm

Big Data
Wasser 4.0



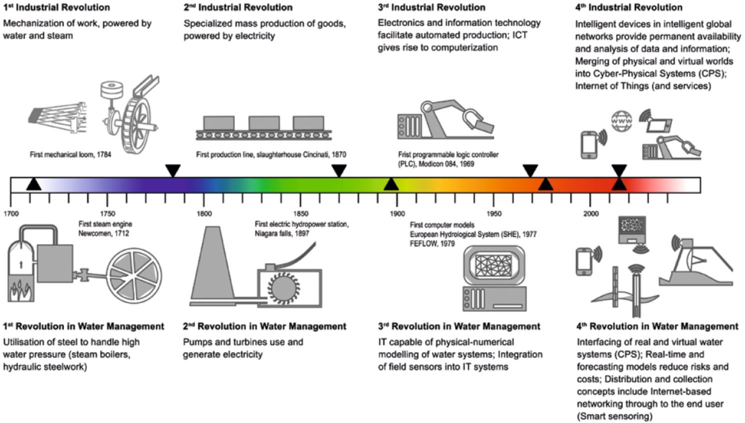
Big Data

Wasser 4.0



Big Data

Wasser 4.0



Big Data

Wasser 4.0

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Views & Comments

Environmental Information Systems: Paving the Path for Digitally Facilitated Water Management (Water 4.0)

Olaf Kolditz [a,b,e], Karsten Rink [a], Erik Nixdorf [a], Thomas Fischer [a], Lars Bilke [a], Dmitri Naumov [a], Zhenliang Liao [c,e], Tianxiang Yue [d,e]

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Big Data

Wasser 4.0 (`www.ufz.de/vislab`)