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“A not completely satisfactory attempt” – peak discharges and rainfall-runoff relations for Javanese rivers between 1880 and 1940

M. W. Ertsen

Water Resources Management, Department of Civil Engineering and Geosciences, Delft University of
Technology, P.O. Box 5048, 2600 GA Delft, The Netherlands

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Abstract. In the early 19th century, the Dutch colonial power started to build irrigation works. A main problem for Dutch irrigation engineers on Java was how to ensure that the structures they built remained intact. The peak discharge regime of a river was an issue closely related to dam safety. Modifying the approach of Swiss engineer Lauterburg (1877), Dutch irrigation engineer Melchior developed a methodology to determine design peak flows of Javanese rivers. The Melchior methodology has been the standard method throughout the colonial period, despite sometimes severe criticisms on its appropriateness. In independent Indonesia, the approach developed by Melchior continues to be applied. This paper discusses and explains the endurance of the method developed by Melchior. The focus is on the scientific interaction between different participants. The paper shows how participants from these circles debated and which arguments they exchanged.

1 Introduction

Irrigation was and is an important support for agriculture on Java, the main island of the most important Dutch colony the Netherlands East Indies – modern Indonesia (see Booth, 1988; Ertsen, 2010; Ertsen and Ravesteijn, 2008; Moon, 2007; Van Oosterhout, 2008). First irrigation efforts were developed by the Javanese. In the early 19th century, the Dutch colonial power started to build irrigation works. One of the first weirs designed by Dutch engineers was built in 1832 in the Sampean River, on the eastern outskirts of Java. The consecutive dams in the Sampean suffered heavily from flash floods – called bandjirs on Java. In 1887 a more or less satisfactory solution was established with a combination of weirs, sluices, river improvements and bypasses, although the Sampean River could still damage the structures considerably. The Sampean story is highly illustrative for a main problem for Dutch irrigation engineers on Java: how to ensure that the structures they built remained intact. The importance of the issue is not just technical, especially when one considers that the unstable character of most Javanese constructions was a main argument employed by engineers to promote their involvement; stability of engineering works was a major political factor in the struggle of engineers to become a respected part of the colonial bureaucracy. The peak discharge regime of a river was an issue closely related to dam safety.

Modifying the approach of Swiss engineer Lauterburg (1877), Dutch irrigation engineer Melchior developed a methodology to determine design peak flows of Javanese rivers.

“*It needs to be put first, that the calculations can never have the goal to determine the largest discharge, which can occur. Such a maximum can not be determined, because meteorological phenomena are not bound to a limit, which can not be exceeded. This relates to an issue of probability. One assumes that the probability of exceeding certain rainfall, wind, temperature, which was not surpassed during a long series of observations, is very small.*” (Melchior, 1895/1896:16; emphasis in original)[1]

In other words, the design peak flow is the flow for which constructions need to be dimensioned; it is not a maximum which would never be exceeded. The Melchior methodology, which will be extensively discussed below, has been the standard method throughout the colonial period, despite

Correspondence to: M. W. Ertsen
(m.w.ertsen@tudelft.nl)

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[1] Dutch quotes are translated by the author.

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sometimes severe criticisms on its appropriateness. The method presented by engineer Der Weduwen (1937) became an attachment to the Melchior standard in the last years of Dutch colonial power, but did not change the foundation laid by Melchior. In independent Indonesia, the approach developed by Melchior continues to be applied. In Irrigation Design Standards (IDS, 1986), an irrigation design handbook of the Indonesian Department of Public Works, the Melchior and Der Weduwen formulas are included as possible methods to estimate river discharges.

In this paper I will make an attempt to explain the endurance of the method developed by Melchior: how can "*a nowise completely satisfactory attempt*" (Melchior, 1895/1896:58) maintain such a successful status as the main – if not only – methodology to be applied for peak river discharge determination? In my reconstruction of the debate on peak discharges in the Netherlands East Indies, I focus on the scientific interaction – exchanges of publications in journals between different participants. Next to irrigation engineers, members from other institutions in the colony have been involved, including engineers from the Sanitation Department and the Department for Hydropower, foresters from the Forestry Service and scientists at the Royal Magnetic and Meteorological Observatory. This paper shows how participants from these circles debated and which arguments they exchanged.

2 Peak discharges on Java

The importance of peak flows connected closely to the natural environment on Java. Most rivers on Java flow from the central mountain ranges to the lowlands to the north or the south, with some of the bigger ones as exceptions – like the Solo or Brantas Rivers. The small north-south axis length of Java implies that the length of Javanese rivers is small. Furthermore, Javanese rivers show large fluctuations in flow, with possibilities of zero and maximum flow within 24 h, particularly in the wet season. Irregular flows of rivers on both seasonal and daily basis were caused by the irregular rainfall pattern on Java; in addition the steep slopes of the upper river catchments were cause of fast drainage of rain water. Such circumstances were not familiar to Dutch engineers.

> "*Until recently research on rainfall-discharge relations, which has been stressed traditionally abroad, was hardly conducted in the Netherlands. Already much research into the relation between tropical storms and discharge waves (the so-called bandjirs) was conducted by Dutch engineers in the former Netherlands East Indies. The little attention for the rainfall-discharge relation in our country is again related to the natural environment. The modified rainfall, the porous soils and the small terrain slopes together are causes for the fact that outflow of rainfall over the earth surface occurs relatively little in our country.*" (De Vries, 1982:9).

In other words, new natural circumstances triggered Dutch engineers to develop new insights. Van Doorn described this urge for new knowledge in general terms and he adds a political dimension to colonial knowledge development.

> "*The Indies were a strange world for the Netherlands. When the colonial project wanted to succeed, it was necessary to collect information and gather knowledge on a large scale. It was always primarily knowledge of direct interest for policy making, either by government, either by large organizations and institutions: intelligence. Such information about the Indies was collected and elaborated on an exceptionally broad scale. As literally everything was strange, sometimes profitable, sometimes threatening, while the native societies offered little or no useful information, the colonizer had to build a complete system of observation, analysis and knowledge spreading. [...] A whole range of tropical sciences emerged from this: tropical medicine and health care, India nor tropical economy, Indian law, Islam studies, Indonesian languages and archeology, botany and volcano studies.*" (Van Doorn, 1994:89).

Van Doorn could have added the field of hydraulic engineering – and civil engineering in general (see Ravesteijn and Kop, 2008). The Netherlands East Indian civil engineers found themselves in a similar position as their British Indian colleagues.

> "*Service in the challenging environment of India was almost a traumatic experience for British officers of intelligence and ability. For some of them, it sharpened their appreciation of engineering techniques and undoubtedly influenced their attitude when they returned to Britain again.*" (Armytage, 1976:167).

Armytage even refers to India as a "laboratory". This metaphor is also working for Java. In a way, colonial Java was an enormous hydrological laboratory, in which the relation between rainfall and river discharges was studied; several Javanese rivers served as experimental sites. Naturally, Java was never perceived nor organized to function as a genuine laboratory. In comparison with genuine hydraulic laboratories, circumstances in which the experiments were conducted on Java were not controllable. Conditions in which measurements were conducted did not remain stable either over time. Already in the 1860s the relation between deforestation and – diminishing – flows in the East Monsoon on Java was discussed in the colony (Van Schaik, 1986). By the end of the 19th century, deforestation caused by plantations – tea, coffee and tobacco – in higher parts of catchments was supposed causing changes in flow regimes, but clearings by the local population were discussed as well. There was growing concern in Dutch colonial circles about an increase in bandjirs over time, both in frequency and extent.

At the same time, flows in the dry east monsoon season became lower, causing problems in several important irrigation areas. In the first half of the 20th century, discussions with inputs from civil and agricultural engineers and foresters from the Forestry Service tried to clarify the relation between East Monsoon flows and catchment characteristics, especially vegetation. Possibilities of reforestation for discharge regulation were discussed, as were engineering measures which could protect river catchments against erosion. Another potential engineering solution to cope with East Monsoon deficits was constructing reservoirs in rivers; surpluses of water from the West Monsoon could then be released in the East Monsoon. The Dutch have built some reservoirs; others have been built in Indonesia after independence.

Despite occasional attention for diminishing flows in the East Monsoon, the irrigation design oriented debate within the hydrological domain focused on determining river peak discharges, basically – although theoretically not exclusively – a West Monsoon phenomenon. As knowledge on the behaviour of Dutch rivers was not applicable on Java, and results from measurements were only available to a limited extent, the Dutch tried to develop a way to determine potential maximum peak flows and thus water levels through calculations. Still based on a limited number of data, at least these calculations gave results which could be applied in design procedures and calculations. Calculation methods like Melchior, the main topic of this paper, transform some type of rainfall event into the resulting river discharge caused by this rainfall event, with a mechanism described in a formula translating rainfall into discharge. Nowadays such an approach would be referred to as a rational method (Institute, 1983). The discussions in the East Indies concerned questions like which rainfall event would be typical, how rivers behaved, and what influence the catchment would have were all discussed. As the Dutch engineers did not have a readily available formula for Java, they looked across their borders to find a suitable method.

3 The early approaches – 1887 to 1917

In a letter dated 8 July 1887 to A. G. Lamminga, engineer Hesked – Head of the Irrigation Brigade – at Java refers to

"*some very peculiar announcements [. . .] of Robert Lauterburg Engineer in Bern, on tests done by him to calculate, under all possibly thinkable circumstances, the largest expectable discharge in* m^3 *per second per square kilometer of the catchment*"

in the "*Allgemeine Bauzeiting*" of that same year[2]. Lauterburg had defined three rainfall events: an event of 50 mm per 24 h for 4 consecutive 24 h periods; an event of 259 mm in 24 h; and an event of 2.1 mm per minute for one hour. Applying certain reduction factors and a factor α taking into account the porosity of the catchment, Lauterburg calculated expected discharges per km^2 for each situation. The results of Lauterburg showed Heskes that a figure of about 2 to 2.5 m^3 per km^2 for catchments between 150 and 300 km^2 was reasonable. This figure had been used before for Javanese circumstances. For smaller catchments, however, Heskes concluded that

"*the largest expectable discharge per* km^2 *can be considerably larger than usually assumed.*"[3].

Just a few years later, in the early 1890s, Dutch engineer De Meyier included the Lauterburg formula in his "*Bevloeiingen*" (De Meyier, 1891:71–74; Van Maanen, 1931). He included another formula as well, drafted by Iszkowski; this last formula applied mean annual rainfall. Despite this dual recognition by De Meyier, one of the most influential Dutch irrigation engineers of those days, Melchior preferred Lauterburg above Iszkowski. To Melchior, maximum discharges could not depend on mean annual rainfall; it would be highly coincidental if maximum rainfall would be related to mean rainfall. Furthermore,

"[t]*hey* [the formulas of Lauterburg; MWE] *are also the ones, which usually are applied by my colleagues and, for lack of studies whether the formulas developed in Switzerland, are also applicable on Java, usually unchanged.* (Melchior, 1895/1896:15)

Melchior continued:

"*This is not rational. It would e.g. be all too foolish to apply those formulas for designing works in Egypt or Arabia unchanged.*" (Melchior, 1895/1896:15; emphasis in original).

Melchior suspected that the – Swiss – results of Lauterburg would be too low for a – tropical – region like Java;

"*yet many designers are already shivery to apply the formulas referred to here in their full consistency.*" (Melchior, 1895/1896:15–16).

Interestingly enough, general opinion in Java was that for smaller catchments, Lauterburg would calculate peak flows too high (Melchior, 1895/1896; Van Maanen (1931) refers to "smaller" catchments as those below 300 km^2).

In his attempt to improve the calculation approach, Melchior developed an iterative process combining graphical and numerical steps (see annex for details). The catchment surface was determined using maps. An ellipse was drawn around the catchment, with the short axis at least being 2/3 of the long axis. Furthermore, length and average slope of the river were needed, excluding the highest 10% of the

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[2] National Archives, Collection 2.22.07, Inventory Number 28 (Letter of Heskes, 8 July 1887; 1; underlining in original)

[3] NA 2.22.07 Invnr. 28 (Letter of Heskes 1887:4)

Table 1. Peak discharges of Javanese rivers as calculated by the methods of Lauterburg and Melchior (Melchior, 1895/1896:57).

River	Surface catchment (km^2)	Observed maximum discharge	Maximum Lauterburg	Difference	%	Maximum Melchior	Difference	%
Kambeng	10.5	51	147	+96	+188	57	+6	+12
Pendil	23	109	248	+139	+128	105	−4	−4
Djogonalan	31	60	291	+231	+385	77	+17	+28
Pategoean	54	130	370	+240	+185	204	+74	+57
Tangsi	60	247	384	+137	+55	260	+13	+5
Babakan	74	448	410	−38	−8	304	−144	−32
Kaboejoetan	76	525	413	−112	−21	273	−252	−48
Tjatjaban	81	592	421	−171	−29	340	−252	−44
Waloeh	109	700	453	−247	−35	166	−534	−76
Sragi	134	283	473	+190	+67	415	+132	+47
Kedoeng-Larangan	145	330	477	+147	+45	313	−17	−5
Djengkellok	150	658	480	−178	−27	407	−251	−38
Pekalen	169	318	492	+174	+55	375	+57	+18
Genteng	178	1190	496	−694	−58	488	−702	−59
Sragi	185	332	498	+166	+50	456	+124	+37
Progo	482	346	603	+257	+74	727	+381	+110
Tjomal	543	1500	663	−837	−56	858	−642	−43
Toentang	620	1080	737	−343	−32	682	−398	−37
Serang	845	2000	932	−1068	−53	668	−1332	−67
Pemali	887	963	956	−7	−1	977	+14	+2
Sampean	1196	500	1189	+689	+138	949	+449	+90
Tjimanoek	3320	900	2412	+1512	+168	1025	+125	+14
		Arithmetical mean			84%			40%
		Algebraic mean			+55%			−2%

catchment. Rainfall data were needed; the catchment runoff factor α was set at 0.52. The Melchior formula reads

$$Q = \alpha\, q\, F \tag{1}$$

Q represents the peak flow to be calculated (in m^3/s)
F represents the surface of the catchment (in km^2)
q represents the expected highest local rainfall (expressed in $m^3/km^2\,s$)
α represents that part of the rainfall flowing directly to the river (without dimension).

At the end of his extensive article Melchior compares his results for Javanese rivers with those obtained applying Lauterburg (Table 1). As the discussion focused on applicability of calculations for peak flows, the arithmetical mean of the percentages was important. The algebraic mean could give a very low value, but could hide enormous deviations for individual rivers. Melchior included the algebraic mean just to indicate whether it was positive or negative. To him, a positive value was indeed positive, as it meant that calculated peak flows were higher than measured flows and design values thus safer. Perhaps even more important, it also meant that in the future – when measured peak flows typically would become higher – the algebraic value would decrease. The arithmetical mean for all rivers in the table of Melchior was lower than Lauterburg.

"*From this perspective the values found by Lauterburg are preferable above mine.* [...] *The matter looks different, however, when one distinguishes between on one side the 12 rivers located in the areas of Tegal, Pekalongan and Semarang and the 10 remaining rivers (Kambeng, Pendil, Djogonalan, Pategoean, Tangsi Kedoeng-Larangan, Pekalen, Progo, Sampean, Tjimanoek) on the other side.*" (Melchior, 1895/1896:58; emphasis in original).

For the 10 rivers on the north coast of Java, the results of Melchior were better in line with measured values, although still high. For the other 12 rivers, matters were different. Lauterburg was already low, but the figures calculated by Melchior were even lower. Melchior mentioned possible explanations, including wrong dimensions of catchments, locations of rainfall measurements which were not representative for higher parts of catchments and less porous soils, but he had to conclude that.

"[t]*o what this is to be ascribed is not known to me.*" (Melchior, 1895/1896:58).

All in all, Melchior saw enough issues to be solved yet, reason for him to consider his work as

"*a by no means completely satisfactory attempt to derive the solution for this issue.*" (Melchior, 1895/1896:58)

4 The success of Melchior

Not completely satisfactory it may have been, the Melchior approach must have fallen on fertile soil: in 1914, the "*Waterstaatsingenieur*", the engineering journal which had just been established one year earlier, published a short manual-type description of the method. From 25 pages in the original Melchior paper – excluding figures – the topic itself had been reduced by Nijman to 3 – excluding figures. The main reason was that the original Melchior article was not available anymore and

"*many younger engineers thus remain ignorant about this method, whereas furthermore the need for a short overview of the paper was often felt, the author, after being requested to do this, prepared the following summary.*" (Nijman, 1914, 1933:325).

Just a few years after Nijmans publication, reports were published in which measured peak flows were much higher than determined with Melchior (for example Redactie (1915) and Feber (1916)). Feber (1916) mentions, that local rainfall could have caused a flood of about 900 $\mathrm{m}^3\,\mathrm{s}^{-1}$ in the Pekalen River. The flow could not be measured exactly, as it flooded the weir itself, but the Melchior method only gave a peak flow of 372 $\mathrm{m}^3\,\mathrm{s}^{-1}$! Feber saw coefficient α as the main cause for this difference; it was raised to 0.60 because of the event he described. The new reports show the importance of empirical data in the development of hydrological science and methods on Java.

In theory, Melchior could give reliable results, were it not that Melchior and his immediate successors possessed the data required only sporadically. Melchior had to replace missing data with several assumptions. Even available data were probably not always that good. Rainfall measurements were scarce enough already, but most of them were daily totals. For peak flow calculations, however, one needs to know the duration of the rainfall event and the – change in – rainfall intensity during the event. As the intensity is highly variable, self-registering rain measurement devices were welcome. However,

" [...] *on Java rainfall observations with self-registering rain-gauges (system Hellmann) are being conducted since 1902 by the Magnetic and Meteorological Observatory in Batavia, at first just on three stations (Batavia, Buitenzorg, Pasoeroean), later on many more. Only in Batavia a less well functioning self-registering gauge was available between 1879–1902.*" (Van Kooten, 1927:21)

Melchior made a number of assumptions to draw the shape of his graphs, for example that mean maximum rainfall for different time spans on unlimited surface were proportional to the normal rainfalls of Batavia for similar time spans. Another assumption was based on data from Europe, in which the intensity at 3 km from the centre of the shower appeared to be half the centres' intensity. Showers on Java have different characteristics, making the assumption questionable (Van Kooten, 1927). Other assumptions that Melchior made was that the ratio between river length and time span of maximum rainfall was proportional to the velocity at maximum water level in the lowest river section. Finally, discharge coefficient α was set by Melchior at 0.52. A foot note in Nijman (1933) states that a value of 0.52 is occasionally low and that a value of 0.62 might be better. In some cases, a value for α of 0.80 would have been more realistic! Changes in α over time – as a consequence of changing catchment characteristics – were discussed thoroughly in the Netherlands East Indies as well.

In "*De Waterstaatsingenieur*", the short time span between 1916 and 1919 saw several authors presenting their views to the issue of discharge calculation. Together these publications represent a small peak in publications on peak flows on Java. Besides being lengthy, the contributions have in common that they do not offer alternatives for Melchior, but discuss the assumptions made by Melchior. A first contributor is De Meyier (1916), who discusses rainfall and runoff factors applied in the Melchior formula, without referring explicitly to the formula itself. Elaborate as the contribution of De Meyier might be, it was neglected by later contributors. The discourse in the next few years was dominated by two persons outside the inner circle of irrigation engineers. In the period 1917–1919 engineer Perelaer, head of the Sanitation Unit of the Department of Public Works and dr. Boerema from the Royal Magnetic and Meteorological Observatory fought their own personal struggle on the subject.

5 Perelaer versus Boerema – 1917 to 1919

In his first contributions on rainfall and runoff, Perelaer (1917a and 1917b) starts with a discussion how to model rainfall on Java; he explicitly makes two assumptions on the relation between surface area and rainfall on this area. First, for smaller areas mean rainfall intensities decrease with increasing rainfall duration; second, for larger areas mean rainfall intensities decrease when the area is increased. Based on these assumptions, his first approach to model rainfall intensities against duration was a hyperbolical curve. When taking a closer look at available rainfall data, however,

"*one immediately encounters the difficulty that these results show insufficient relation with the preconceived assumption of hyperbolic development.*" (Perelaer, 1917a:280).

Perealers' explanation was that the rainfall peak intensities measured were probably not those peaks occurring in the centre of the shower; it would be highly unlikely if the centre of a shower would be precisely above the rainfall measurement gauge. Therefore, he expected that measured values were too low to represent possible peak intensities in the centre of the shower. Thus, he set this value higher than the maximum intensity measured – at 12.3 mm per minute against 9 mm per minute measured. Furthermore, rainfall measurements for longer periods on different locations on Java made Perelaer set the maximum intensity of 24 h rainfall events at 432 mm per 24 h – or 0.3 mm per minute – assuming that

> " *– at least for these regions – the character of large rain showers is location independent*" (Perelaer, 1917a:281).

Perelaer simply applied the method of Melchior, but as he assumed higher rainfall his peak flows were much higher than those calculated by Melchior – or Lauterburg. Perealers' values fitted with several measurements in Javanese rivers – like Pekalen or Sampean –, but for other rivers the potential peak flows found by him were considerably higher. Boerema (1918a) challenged the rainfall assumptions of Perelaer, not his runoff calculations. Boerema plunged into the matter directly in his introduction:

> "*It appears to me, however, that the assumptions of mister Perelaer on the highest expectable rainfall cannot be plead free from arbitrariness, that the existing observations, which after all give the only foundation for distracting data on rainfall, are hardly used at all and that the assumptions occasionally go against observations or lead to conclusions, which hardly coincide with observations.*" (Boerema, 1918a:254; emphasis in original).

After discussing the validity of the peak intensity measurements themselves, Boerema questioned the assumption that a rain shower would have one centre with highest intensity.

> "*The heavy rains emerge by powerful rising movement of moist air and it cannot be assumed that as a rule a small pillar with a much higher rising speed will occur in this column.*" (Boerema, 1918a:255).

Referring to the rainfall atlas for Java (Van Bemmelen 1915), Boerema also refused the assumption that bigger showers on Java would be independent from location. An intensity value of 432 mm per 24 h – or 0.3 mm per minute – would be too high for most Javanese areas. Boerema promise to give an elaboration of his approach to determine maximum rainfall in a forthcoming issue of "*De Waterstaatsingenieur*" was fulfilled in the same year (Boerema, 1918b); the article was preceded by a reaction of Perelaer to the first publication of Boerema (Perelaer, 1918). Perelaer acknowledged some of Boeremas remarks, but not those concerning his assumptions regarding rainfall intensities. For both assumptions – respectively peak intensities per minute and for a 24 h period – Perelaer explained that he was interested in the highest possible values. Perelaer argued that Boerema discussed differences in frequency of rainfall events, not rain shower patterns on Java. When Perelaer assumed maximum rainfall intensities for all Java, he did so without implying that this maximum event would occur with a similar frequency on all locations;

> "[...] *there is difference in frequency, but for no place such rainfall is definitely excluded.*" (Perelaer, 1918:442; emphasis in original).

To him the defined maximum of 432 mm per 24 h could occur on the whole of Java, but more often in some regions than in other.

> "*The amount of rainfall during a certain time frame is a matter of probability*" (Perelaer, 1918:439).

In his final contribution, Perelaer (1919) stressed this difference in approach when he criticized Boerema (1918b), in which Boerema reconstructed the mean maximum rainfall events for several locations in the Netherlands East Indies.

> "*For the averages thus accomplished I want to assume that they give the relation between highest rainfall and time, when one ignores local differences.*" (Boerema, 1918b:449).

Perelaer considered it "[n]*ot particularly rational* [...] *to start with mean figures and therefore I looked for the highest observed intensities*" (Perelaer, 1919:87/88).

Perelaer would typically calculate the absolute maximum possible for rainfall and this runoff; it was already the founding father Melchior himself who stated that determining such maxima was not the issue:

> "*In case it* [the exceeding value] *does occur, a "catastrophic high water" does happen in a river, than one can resign with this without blaming oneself. Even in case repairing the resulting damage costs more than the extra sum which would have been necessary to spend to make the work resisting the larger discharge from the beginning, even then one can comfort oneself with the thought that in case one would have put the demands much higher, one would have fixed large sums without use in other works, for which such unforeseen circumstances did not occur.*" (Melchior, 1895/1896:16).

6 Hydropower enters the debate

The discussions above were restricted to the input side – rainfall – with some attention to the formula resulting in peak discharge values. With a new player entering the engineering field in the Indies, river behaviour and discharges started to receive considerable attention too. One of the main activities of the Department for Hydropower, established in 1917, was developing a systematic measurement program for rivers in the East Indies. The availability of self-registering water level equipment proved a great help (Herz, 1922; Groothoff, 1918). Sound data on discharges were already important for irrigation, but even more so for hydropower. Hydropower needed a guarantee that the – very expensive – equipment can produce electricity almost continuously, particularly during periods of low flows. Furthermore, the equipment needed higher protection levels than irrigation works in case of floods. Particularly for lower discharges, an approach applying a discharge coefficient α would not yield results.

"*After all, in a very dry year one encounters some months without rain and one cannot determine a discharge from this with a coefficient.*" (Van Staalen, 1932:85).

The high investment costs of hydropower infrastructure increased economic risks of electrical power – also for users like European industries and railways – requiring detailed insight in river behaviour. The Hydropower Service employed civil, mechanical and electro-technical engineers, some of which were Swiss. Not all Dutch engineers were in favour of employing foreign engineers. Implicit defences for hiring – only small numbers of – foreign engineers are found too, for example in the many remarks how new hydropower was to the Dutch.

"*Until recently, the hydropower issue had for Dutch technicians something of the unknown, of the mystique, which attracts the normal Dutchman with so much power to the mountains.*" (Groothoff, 1918:32)

Whatever the case, the foreign engineers were there. Engineer Herz was one of them; in his publication of 1922 he is referred to as "temporary engineer" with the Hydropower Service. Herz mentions an earlier paper of himself written in German, which was presented at the Second Netherlands East Indian Congres for Natural Sciences. Herz presented data from six years of river water level measurements with self-registering devices.

"*On its turn insights thus gathered in the process of bandjirs was reason to study the conditions for occurrence more precisely* [. . .]" (Herz, 1922:432).

Herz presented data on peak discharges, which would typically be the result of calculations like Melchior proposed. Herz tried to identify some issues which could potentially improve peak flow calculations. He distinguished 4 types of bandjirs (Fig. 1) (translated from Herz, 1922:433):

Slow bandjirs (diagram a); "*identified by a regular course: the rising velocity is not more than about 1/4 m per hour; no clear culmination point, like the other diagrams show as more or less sharp tops, but usually a highest level, which holds a few hours; and slow, often irregular falling.*"

Normal bandjirs (diagram b); "*the usual course for mountain rivers as occurring in Europe, for example in the Alps, too. Rising takes some hours and happens with a velocity of ±1 m per hour, the highest level takes not more than quarters of an hour, falling is generally regular and almost hyperbolically.*"

Sudden bandjir (diagram c). "*From the normal level the highest level is reached in about 10 to 30 minutes, as good as without slower rising in the beginning. The rising velocity is 1 m in about 5 to 10 minutes, the top is slender, the highest level stays shorter than for a normal bandjir, falling is regularly and very fast in the beginning, although slower than rising, in general again hyperbolically.*"

Extreme bandjir (diagram d). "*The time for rising is read in the diagrams as zero. This would mean that a vertical water wall would flow through the gauging profile, a fact, which needs further explanation in case of considerable heights of such a water wall (cases of 2.5 m were registered).*' As the measurement interval for the measuring devices was about 10 min, the value "zero" in practice meant "occurring in less than ten minutes".

Bandjirs of types c) and d) were supposed to be typical for tropical regions; extreme bandjirs had the special attention of Herz. A model implying rainfall of some longer duration on a larger surface area causing a more or less gradual rise of the water level could not be applied to these bandjirs. As the extremely fast rising time made it impossible to deduct the profile of these bandjirs from measurements, Herz looked for formulae describing the phenomenon. The only reference he encountered was from a German textbook (Forchheimer, 1914), although he included the reference with care, as it was valid for European rivers and

"*so superficial, that one cannot draw conclusions from it.*" (Herz, 1922:436).

Forchheimer gave some results of measurements of the velocity of the wave resulting from extreme rainfall; this wave velocity could perhaps explain the sudden rise of the bandjirs. For European rivers he found that the wave would have a maximum speed of about 1.5 times the normal water velocity, a value not nearly high enough to explain the sudden changes in rivers on Java. This implied that the model of a single heavy shower causing bandjirs was not likely either, as the very quick rise of the water surface would mean that it only rained on a relatively small area – because the travel time of the water was very short. In order to achieve a bandjir, such a small area would require a rainfall intensity of impossible dimensions for Java. To Herz the only feasible explanation for extreme bandjirs was a moving rain shower along the river in downstream direction. Melchior himself had already suggested that this was a possible scenario for peak discharges, but he concluded that

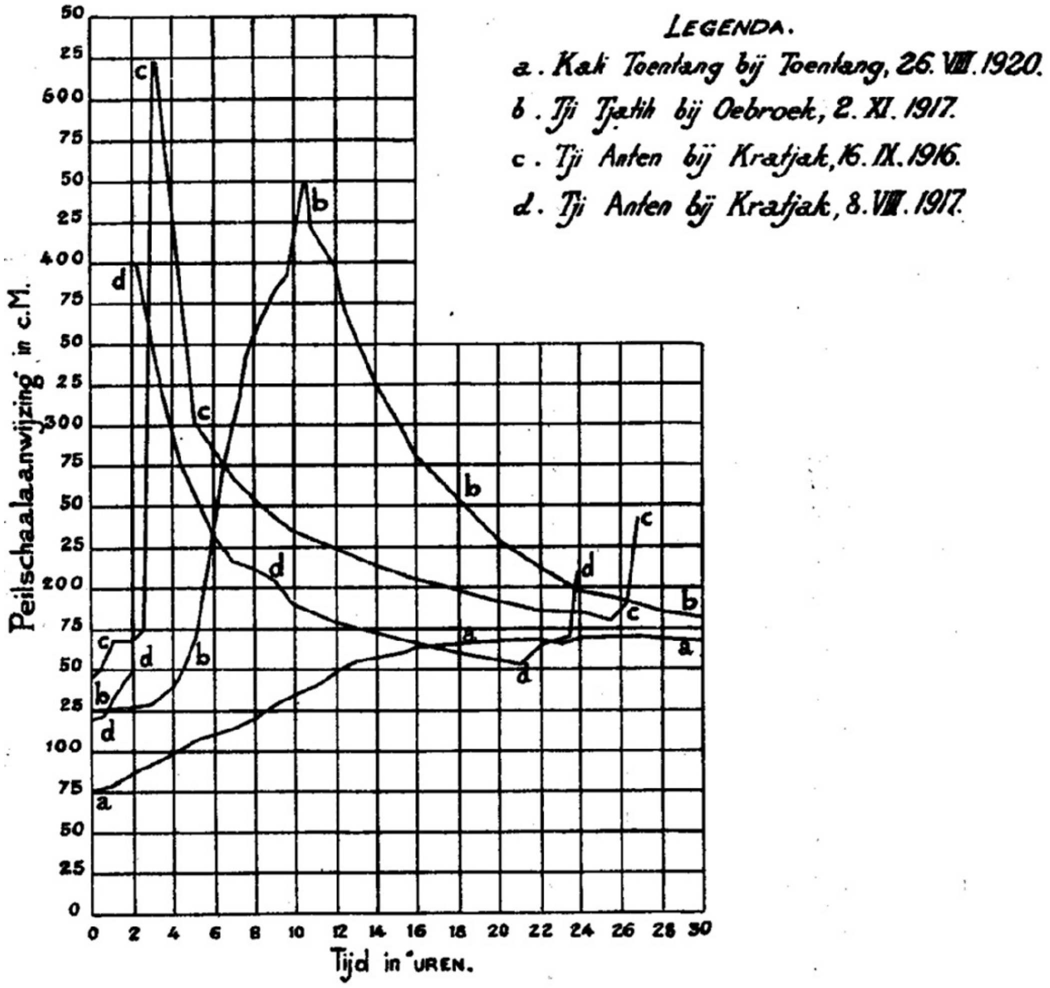

Figure 1. Four types of bandjirs (Herz, 1922) – Vertical axis showing water level changes in centimetres, horizontal axis showing time in hours. Legend describing name of river and month/year of measurement.

"[s]*uch possibilities withdraw from each calculation, because it cannot be determined how far one needs to go in this respect.*" (Melchior, (1895/1896:53) quoted in Herz (1922:437)).

In a second paper, published in 1923, Herz developed a theoretical model to calculate the peak flow for such a moving shower. The approach of Herz seems to have caused little or no reaction by others than Van Staalen (1932), and it is unlikely that Herz would have liked that attention. According to Van Staalen (1932), who like Herz was employed by the Service for Hydropower and Electricity, the method of Herz was

"*worthless*" (Van Staalen, 1932:88).

Furthermore, to Van Staalen it was not very useful to develop methods to calculate discharges

"[w]*hen completely lacking exact observations of moving showers* [. . .]" (Van Staalen, 1932:88).

7 The debate summarized and complicated by Van Kooten in 1927

In his book of 1927, Van Kooten presents an overview of several issues related to rainfall-discharge calculations. Van Kooten elaborates the line of thinking set by Lauterburg and Melchior. One might have expected at least some reference to the article of Herz would have been made in such an extensive overview on rainfall-discharge relations as Van Kooten (1927). Although Van Kooten includes remarks on the influence of position and movement of showers in relation to river discharges, he did not pursue the issue in detail nor did he include Herz in his references. Van Staalen (1932:90) suggests that Van Kooten did not have contact with the Service for Hydropower and Electricity.

In the first chapters Van Kooten discusses several variables needed for calculations; in other chapters he discusses and compares several methods. To take one of the variables needed, one which had created quite some discussions

Table 2. Comparison of different methods to calculate river peak discharges (Van Kooten, 1927).

	Formula type I	Formula type II	Formula type III
Type	"*With the first method the maximum discharge is found by calculating first the factors* α, β, t_m *and* q *separately* [...] *and afterwards determining* Q *by multiplying the product of* α, β *and* q *with the catchment surface area* F. *Thus,* Q *is composed from its constituting parts, for which the formulas must be based on a large number of empirical data on rainfall and floods*" (p. 106)	"With the methods *II, IIIa and IIIb, however,* Q *is calculated as a whole by means of one single formula or equation, in which the numerical values of the coefficients appearing in the equation have to be determined with the aid of preferably as many rivers as possible, positioned in the area in which one wants to apply the formula. Other data are not needed for this.*" (p. 106)	
Rainfall data	"*In the methods mentioned first the highest amounts of rain* R *or* R^l *which can fall in a single shower or in a 24 h land rain is used as standard for the rainfall* [...]" (p. 108)		"[...] *whereas in the last two methods for this standard the total amount of rain* H*, which can occur on average in the whole catchment in a year or slightly shorter timeframe is assumed*" (p. 108)

before, Van Kooten (1927) discusses in detail the nature of rainfall events on Java. For this he compares rainfall on Java with rainfall in countries as Germany and the USA, distinguishing between two types of rainfall: showers – defined as rains within a period of 12 to 14 h of high intensity on a small geographical surface – and land rains – defined as rains from some hours to a few days of lower intensity on a large geographical surface. On Java, rains that yielded maximum flows were short, intensive showers.

"*Depression areas* [...] *are* [...] *not encountered in the Netherlands East Indies and therefore continuous land rains either. The heavy rains, which can be considered for maximum discharges, usually fall here as short rains or showers of maximally 12 to 14 h duration. From the 73 large rain events per 24 h which occurred in Batavia, Buitenzorg, Pasoeroean and Pontianak till 1916, 66 were caused for 90% on average by one single shower of 2 to 14 h duration* [...]." (Van Kooten, 1927:18).

Javanese showers not only had higher intensities and longer periods in comparison to showers in other countries, but also a somewhat larger geographical area. For catchments up to about 100 km^2, this resulted in higher peak flows on Java than compared to flows in central Europe, North America and British India (Van Kooten, 1927). In larger catchment areas on Java, peak discharges were not caused by one single shower, but were generally caused by a number of showers in the catchment area. These showers should fall separately in space and time, for example early ones in the higher catchment and later ones in the lower areas. In such a pattern, late rains would reinforce the effects of early rains; together they would yield a considerable peak flow (compare with Herz, 1922). Java had many small catchment areas with relatively high discharges and some larger catchments with relatively low maximum discharges; differences between smaller and larger catchments were not as big as in other regions though.

"*For example the highest discharge of the Solo River on Java, with a catchment of 15 000 km*^{2}*, is 2300 m*^{3}*, whereas the maximum in catchments of similar size in Central Europe, North America and British India is 2 to 3 times larger.*" (Van Kooten, 1927:19).

In his book, discussing factors in formulas of Lauterburg and Melchior, Van Kooten used a large quantity of data, from countries like the USA, Germany and the Netherlands East Indies. The enormous amount of data must have provided a much better base for analysis than others had been able to achieve before him. Using his data and extensive analysis, Van Kooten discussed three types of formulas (Table 2) along two dimensions: type of formula and type of rainfall data applied. When the necessary river discharge measurements would be available, Van Kooten preferred methods II and III. As, however, such data were hardly available, Van Kooten concluded that

"[...]*one would be inclined to prefer method I*" (Van Kooten, 1927:106).

Melchior is one example in the method I category. For these methods, however, other data would be needed, which were not readily available either. It is not completely clear why Van Kooten prefers one type of lack of data for another; it is likely that he prefers a better known approach – method I – above a new one, until proven that the approach is less usable. It may also be that he prefers method I because it allows analyzing the issue step-by-step; with methods II and III one may get the feeling that the method is a black box. Whatever may be the case, Van Kooten described different ways to calculate maximum river discharges without selecting the best. Actually, he proposed to apply all formulas and select their mean discharge value for design. The discharges calculated were

"*one time the highest or lowest for one of the methods, than again for one of the other methods, so that the four methods are equal in relation to each other in this perspective too.*" (Van Kooten, 1927:108).

Appropriate as this may have been, it is not very likely that design engineers in practice were enthusiastic about the amount of calculations, especially when they needed to apply different data, graphs, formulas etcetera for each calculation. In a way, the work of Van Kooten may be more oriented towards science than towards practice.

Despite its unpractical aspects, the book of Van Kooten was highly appreciated; it was generally recognized as a step forward in the development of hydrological science in the Netherlands East Indies (for example Van Staalen (1932:82)) and quoted by all contributors to the debate to follow. Nevertheless, later contributors had remarks, occasionally on calculations or values for coefficients, sometimes more fundamental. Van Staalen highly appreciated the starting point of Van Kooten that

"*a calculation method will have to be based on observations as much as possibly possible.*" (Van Staalen, 1932:82).

Furthermore, the fact that Van Kooten presented several ways to calculate the peak discharges instead of just one was valued too by Van Staalen. However,

"*my main objection to his work is, that it does not limit itself to what the title promises, viz. methods, but that in the end formulae are given.*" (Van Staalen, 1932:82).

Applying formulae instead of developing a method would reduce flexibility in approaching different situations. Factors in a formula are fixed, whereas a method would allow specific application of factors for each situation. To Van Staalen, the danger of focusing too much on formulas instead of the underlying principles would be that engineers would apply these formulas without considering the appropriateness of them.

8 The entrance of statistics in 1931

To Van Staalen, scientific discussion on methods in hydrology really received an important stimulus by the publication of Begemann in the early 1930s.

"*Herein not formulas are given, but methods and undoubtedly very valuable ones.*" (Van Staalen, 1932:83).

Based on an extensive literature review, Begemann (1931) discussed an approach in hydrology which was new for the Netherlands East Indies: probability – frequency – analysis of events. Although Begemann acknowledges that Melchior had mentioned the issue of probability (see the quote of Melchior above),

"[i]*n the applications (§ 6, p. 52), however, it becomes apparent that no further calculations are made with the frequency.*" (Begemann, 1931:13).

The reference list of Begemann was so extensive that Van Staalen, when referring to the list one year later, apologizes for not having read all the material.

"*It will not be surprising, that not all publications mentioned are known to this author.*" (Van Staalen, 1932:81).

A major criticism of Begemann on the approaches discussed and developed between 1890 and 1930 was that restricting analysis to extreme rainfall and discharge events would yield results with limited applicability. As occurrence of such extreme events was rare and irregularly divided over time, predictions or expectations would be very difficult. Sound analysis therefore had to include all measurements or at least considerable part of them. Analyzing such an amount of data required another approach as taken so far.

"*Utilizing all or a large part of available rainfall data is best to be achieved with the aid of probability theory.*" (Begemann, 1931:14).

Analysis of probabilities of occurrence of events was supported by the development of several types of probability paper, each applying some kind of logarithmic scale. Begemann discussed results of applying probability paper for several issues – rainfall, discharge, reservoir use. His article includes many curves, graphs and results. For frequency analysis of river discharges and water levels Begemann used measurements from the Toentang and Serang Rivers in the Demak area. Some discharge values had to be reconstructed as available data gave water levels above crest level of the weirs in the rivers – Glapan in the Toentang River and Sedadi in the Serang River – instead of discharges. Most data were collected by lower Javanese irrigation personnel. Begemann considered measurements done them

"*almost worthless* [...] *when not sharply and regularly controlled*" (Begemann, 1931:69).

This was reason for him to recommend applying self-registering water level devices. After analyzing rainfall and discharge separately, Begemann related rainfall and discharge. Based on a map showing rainfall values exceeded every 25 years, Begemann calculated discharges for the Kali Majong and Kali Logoeng applying the insights of Van Kooten. After comparing these values with those from the original Melchior formula and measurements, Begemann drew duration graphs of river discharge and rainfall on probability paper. For the Kali Logoeng, the curves were more or less parallel, for the Kali Majong this was clearly not the case. As Begemann expected that the curves should not diverge too much – higher divergence would mean that the discharge behaviour of a catchment would change drastically with changes in rainfall – he considered the results for the Kali Logoeng as satisfactory. The divergence of the results for the Kali Majong would be the result of unreliable discharge measurements, which reinforced the argument to apply self-registering devices.

Linking duration curves for rainfall and discharge, Begemann determined return times of peak discharges. Begemanns assumed that rainfall data and topographical information for river catchments were available on Java. Discharge data were still rare. If one would conduct measurements on river discharges for some years together with rainfall measurements, however, one could reconstruct the total discharge duration curve for the longer period based on the reconstructed relation between rainfall and discharge curves for the shorter period. The relatively low accuracy of the short series of discharge measurements would be compensated satisfactorily with the longer series of rainfall data. Doing extra discharge measurements was especially worthwhile for larger designs like irrigation systems; after all, time periods for such projects were in the order of years. For smaller constructions like bridges, Begemann suggested to keep the Melchior-like formula as single application, although he acknowledged the difficulties to determine the coefficients – α in particular. In his 1932 article, Van Staalen suggests a similar division of approaches.

Despite his relatively straightforward design applications, the Begemann approach remains somewhat of a sideline in written sources of the time. Apart from reference to his publication as a splendid piece of work presenting the best method (for example Verweij, 1939:II.100; Kras, 1940:II.48), application in reports or public writing are missing. The wealth of material presented by Begemann may have caused some doubt with the readers of his time whether they would be able to apply the method, although Begemann assured that

"[t]*hese methods can be applied by every engineer, as the work is mostly graphical and most difficulties and objections to applying curves and equations based on statistical methods of analysis are avoided.*" (Begemann, 1931:17/18).

Engineer Schoemaker, however, who worked in the East Indies just before World War II and was professor of irrigation at Delft Polytechnic between 1967 and 1984, confirmed that he and his colleagues did apply the statistics of Begemann; the need to apply Begemann was included in a letter from the Department of Public Works.

"*With the application of the statistical description from 1931 a weir was designed with a probability of occurrence of 1.4% and a freeboard of the sidewalls sufficient to cope with a discharge of 0.5% probability without damage.*" (Letter Schoemaker to author, 15 November 2004:4)

9 Melchior remains in use, an additional method emerges – 1930 to 1940

After Begemann, the well-known Melchior approach did not disappear. The resume of the Melchior method published in 1914 reappeared in the last issue of De Waterstaatsingenieur of 1933. The article is an exact reprint of the Nijman article of 1914;

"*The fact that both the original article of Ir. Melchior and the resume prepared by Ir. Nijman are since long exhausted is felt as a serious gap, which becomes apparent through the many demands which reached the Administration of our journal last years. Therefore, the editors think to meet the wish of many by including in the latest issue a reprint of the resume referred to.*" (Footnote with Nijman, 1933:325; emphasis in original).

The discussions in the late 1930s were again directed at improvements of the original Melchior method. In an article published in 1937, Der Weduwen proposed a method which

"*thanks her origin from the desire to reach a simple nomographic solution for calculating the maximum discharge of smaller catchments, in which the slope of the discharge, t.i. the terrain slope, is taken into account.*" (Der Weduwen, 1937:II.139).

According to Der Weduwen, the Melchior method did not weigh the terrain gradient enough; particularly for smaller catchments this gradient would be influential. Data from the Service for Hydropower showed that discharge time was influenced by the terrain gradient, but available data were insufficient to define an empirical formula for this relation. To be able to draw a design graph, Der Weduwen needed to establish relations between catchment surface area and rainfall surface area, and between river length and catchment surface area.

"*As there is no fixed relation between the factors mentioned above,* [. . .] *an assumption is made for both, based on relations known for a large number of catchments.*" (Der Weduwen, 1937:II.139).

This assumption restricted the applicability of the graph to catchments smaller than 100 km^2. Basically, Der Weduwen proposed an adapted Melchior method, not a new one – although he included frequency issue elaborated by Begemann to some extent. As Der Weduwen used Batavia rainfall data, strictly speaking the applicability of his nomograph is restricted to the Batavia area, as he himself acknowledged. Despite this, Der Weduwen did not hide his hope that his method would be used for all Java. Indeed, very soon his hope had become reality, when his method began to be figure as Public Works standard for small catchments,

"*a.o. as a result from a letter of the Director of Public Works dated December 7 1937 (no. E 33/15/15)*" (Kras, 1940:II.46).

In 1939, Verweij remarked that Der Weduwen

"*has strived too much to composing one, easily manageable graph and therefore was forced as it were to make too many simplified assumptions*" (Verweij, 1939:II.99).

In a response, Verweij developed his own method – although he thought that Begemanns approach was preferable – and slightly adapted Melchior method, as he applied rainfall values defined with Begemanns frequency analysis. Another engineer, Kras, shared objections to general application of the Der Weduwen method, amongst others because the method assumed a certain standard division of rainfall over the day, but concluded that

"*one will have to step over these objections given the lack of data.*" (Kras, 1940:II.46).

Thus, even as late as 1940, lack of data appeared as a main argument to choose a certain simplification. This same lack of data was reason for Kras to consider applying Begemanns method as impossible most of the time! The contribution of Roessel (1940) to the hydrological debate also mentions lack of data. Roessel, a retired Chief Forester, compared results obtained with Melchior, Van Kooten and Der Weduwen with empirical studies. Applying many data from several studies, Roessel showed that all three formulas had weaknesses compared with measured data. An obvious factor of uncertainty was discharge coefficient α, but Roessel also showed that all approaches were not very successful in calculating travel time of the bandjir T or T_w. His extended discussions make him remark, that

"[i]*n this way many questions can still be asked, which are not answerable for the moment.*" (Roessel, 1940:II.128).

He proposed to study both travel time and discharge coefficients further.

10 The persistency of the Melchior method explained

This paper tells a story of persistency of the Melchior methodology in the Netherlands East Indies. Despite discussions, alternative methods or calculations and occasionally criticism, the methodology remained in use in the Netherlands East Indies throughout the colonial period. What could have been reasons for this survival? A first explaining factor may be found in the alternatives offered in the discussions on the methodology. Although Der Weduwen developed an alternative for small catchments, which became a standard too, his approach was an addition and not a change of the method of Melchior. Those contributors that did offer alternatives either recommended using four formulas (Van Kooten) or provided a perfect alternative which was generally regarded as not applicable (Begemann). Most participants in the debate did not offer an alternative for Melchior anyway, but discussed certain elements of the approach, like how to define rainfall as input. Furthermore, signs of a certain inertia in irrigation engineering circles cannot be ignored. A general feeling of lack of data, expressed by so many authors, may have stimulated the application of well-known methods which gave usable answers.

Well-known methods may give results known not to be completely accurate, but given time constraints in design, methods demanding little time with reasonable results were very welcome, like the Der Weduwen nomograph.

"*A larger accuracy is not a requirement either, as still many uncertain factors occur in the further course of the calculation of the discharge, one only needs to think off runoff coefficient α.*" (Kras, 1940:II.49).

In terms of contributors to the debate, contributions from relative outsiders (Perelaer, Boerema, Herz, Van Staalen) are discussed, but the mainstream of discussions on rainfall and peak river discharges was dominated by irrigation engineers. Begemann attempted to combine the world of the irrigation engineers, with most attention for peak flows and a focus on rainfall-runoff relations and the world of hydropower engineers, with attention for the general river flow patterns to determine maximum yields for electricity production. Many contributors in the debate imported results from other areas, as data for Java were not always available. The Alps and its direct surroundings were the main alternative open air laboratories for Java. Begemann included another region, the United States of America. He remains an isolated case, however, when it comes to this geographical preference.

The final, and most extreme call to use Javanese rivers as one giant open air laboratory is made by Roessel (1940). His proposal to study travel times is interesting, as it suggests a different position of man-made irrigation systems in the Javanese natural environment at the end of the colonial period.

"*In general one would do better to collect the necessary empirical data* [on travel time of floods; MWE] *by means of artificial floods. In a country where irrigation plays such an important role as on Java it will be easy enough to find locations where one can generate such artificial floods. In case one suddenly closes off an off take in a small mountain river, one receives in the river itself a sudden flood. One only has to check when the flood arrives a few km further.*" (Roessel, 1940:II.129).

Roessel thus proposed to use irrigation works, the same works that were threatened by bandjirs and as such gave main stimulus to develop methods for peak discharge determination in the first place, for optimizing these methods 50 years later. The proposal of Roessel would transform irrigation systems into instruments within the bigger laboratory Java. From the idea to create artificial peak flows back to Melchior seems like a big step. However, when we consider that Roessel wanted to determine travel times of peak flows, the step becomes much smaller. After all, it is this travel time – in relation to rainfall duration – which was one of the most difficult problems to solve for Melchior. Rainfall measurements, when available, could give the information needed on intensities on different times and places, but travel times of flows required detailed measurements, which were not available to Melchior. He simply had assumed that he could relate travel time to river flow velocity at peak discharge.

"*In the instructions from the Service this elaboration was shortened with a table with percentages to enlarge the outcomes of the first calculation depending on the catchment.*" (Letter Schoemaker to author, 15 November 2004:4)

All later authors faced similar difficulties with the time element. The estimation of Melchior was rough, but his predecessors could not come up with better estimations. Another difficult element in Melchiors approach, as it was difficult to measure, was factor α, the runoff coefficient. Melchior set the standard value of this retention factor at 0.52; his predecessors, being confronted with higher peak flows for similar rainfall events, set the value higher (compare with Nijman, 1933). Adapting this α factor, however, was not a change of method, but merely an improvement.

11 To good a method?

A final reason for Melchiors endurance may simply be that the method itself was not too bad.

"*One could add, speaking exaggeratedly, that it is to a certain extent regrettable, that this first Indian study was so exceptionally good, taken into account, to repeat it, the data which were available.*" (Van Staalen, 1932:81).

A 1983 flood design manual (Institute, 1983) still stated that, despite some constraints,

"*the Melchior approach for catchments greater than 100 km^2 produces reasonable results on the whole* [. . .]" (Institute, 1983:66).

According to the same manual

"[t]*he Der Weduwen method does not perform particularly well and appears to consistently overestimate floods*" [. . .]. (Institute, 1983:66).

Although his method appeared to be open for critique, Melchior remained an engineer highly esteemed by his successors. They might not have taken the results of his approach for granted, but Dutch irrigation engineers honoured the way he approached the subject of peak flow determination. Melchior received the Conrads price from the Royal Engineering Institute for his study, as the first engineer from the Netherlands East Indies receiving that honour (Melchior, 1932). Melchior was one of the first Dutch irrigation engineers who introduced a scientific approach to solve problems encountered in practice, even when his goal was to develop a practical method. He was well aware of limitations of his method, as he himself regarded it as a not completely satisfactory attempt to solve the problem. Engineer Ott de Vries expressed this general feeling of estimation for Melchior in his funeral speech:

"*Melchior, now we have to take leave from you, I must primarily thank you on behalf of the Indian Public Works engineers of now and the future for the pioneering work that you have done on their area and for the Indies and I can furthermore assure you that they will always be proud that your name stands forth in the register of names of the Indian Public Works engineers.*" (Melchior, 1932:36; emphasis in original).

Archival material

National Archives, The Hague, the Netherlands: Collection Haringhuizen-Schoemaker (nr. 2.22.07); Inventaris van een verzameling stukken betreffende openbare werken in Nederlands-Indië en Suriname afkomstig van het Instituut voor Waterbouwkunde in Delft over de jaren 1872–1970 (verzameling Haringhuizen – Schoemaker)
Inventory number 28 Dossier XXVI. Archivalia van ir. A.G. Lamminga: "Rapporten voorbereiding Pekalenwerken" (Probolinggo). 1883–1887: Letter of 8/7/1887, Departement der Burgerlijke Openbare Werken, Irrigatie Brigade, No. 289, 1 bijlage; Letter of Henkes to A. G. Lamminga, with subject the Lauterburg method

Appendix A

The Melchior calculation routine

1. The catchment surface $F = 169\,\mathrm{km}^2$.

2. The long ax of the ellipse is 28.4 km, and the short ax is taken as $2/3 \times 28.4 = 18.9$ km. The ellipse' surface becomes $nF = 1/4 \times \pi \times 28.4 \times 18.9 = 422\,\mathrm{km}^2$.

3. River length $L = 39.2$ km. Without the highest 1/10 of the catchment, the remaining 35.3 km passes a height of about 1700 m, thus slope $i = 1700/35300 = 0.0480$.

4. Maximum rainfall of the four stations inside or just outside the catchment is respectively 146, 165, 244 and 236 mm, resulting in a mean maximum rainfall $h = 1/4(146 + 165 + 244 + 236) = 198$, say 200 mm.

5. First approach, with Table A1 and $nF = 422\,\mathrm{km}^2$: q set at value $3\,\mathrm{m}^3\,\mathrm{km}^{-2}\,\mathrm{s}^{-1}$. Thus $Fq = 169 \times 3 = 507$. With $i = 0.0480$, and Fig. A1, $v = 1.35\,\mathrm{m\,s}^{-1}$. Than $T = 1000L/60v = 39200/(60 \times 1.35) = 484$ min. From Fig. A2, $q = 3.8\,\mathrm{m}^3\,\mathrm{km}^{-2}\,\mathrm{s}^{-1}$.

6. With this value for q as input, the calculation is repeated. Results are $Fq = 169 \times 3.8 = 642$, $v = 1.42$, $T = 460$ min, $q = 3.95\,\mathrm{m}^3\,\mathrm{km}^{-2}\,\mathrm{s}^{-1}$. Another repetition with this last value of q does not result in a more secure value, giving $q = 3.95\,\mathrm{m}^3\,\mathrm{km}^{-2}\,\mathrm{s}^{-1}$ as the value to be taken. As $T = 460$ min, 8% must be added to the value of q (Table A2). The final $q = 4.27\,\mathrm{m}^3\,\mathrm{km}^{-2}\,\mathrm{s}^{-1}$.

7. The total peak flow is calculated as $Q = \alpha F q = 0.52 \times 169 \times 4.27 = 372\,\mathrm{m}^3$.

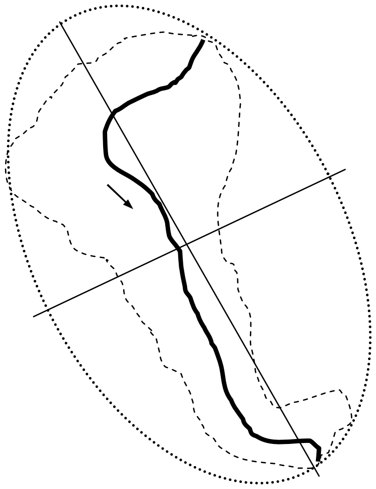

Figure A1. Catchment area and ellipse as drawn in step 1 of the Melchior method.

Table A1. Design values for Melchior to convert the surface area of the ellipse nF to typical discharge per surface unit q (Nijman, 1933).

nF (km^2)	q (m^3 km^{-2} s^{-1})	nF (km^2)	q (m^3 km^{-2} s^{-1})	nF (km^2)	q (m^3 km^{-2} s^{-1})
0.14	29.6	144	4.75	720	2.3
0.72	22.45	216	4.0	1080	1.85
1.4	19.9	288	3.6	1440	1.55
7.2	14.15	360	3.3	2160	1.2
14	11.85	432	3.05	2880	1.0
29	9.0	504	2.85	4320	0.7
72	6.25	576	2.65	5760	0.54
108	5.25	648	2.45	7200	0.48

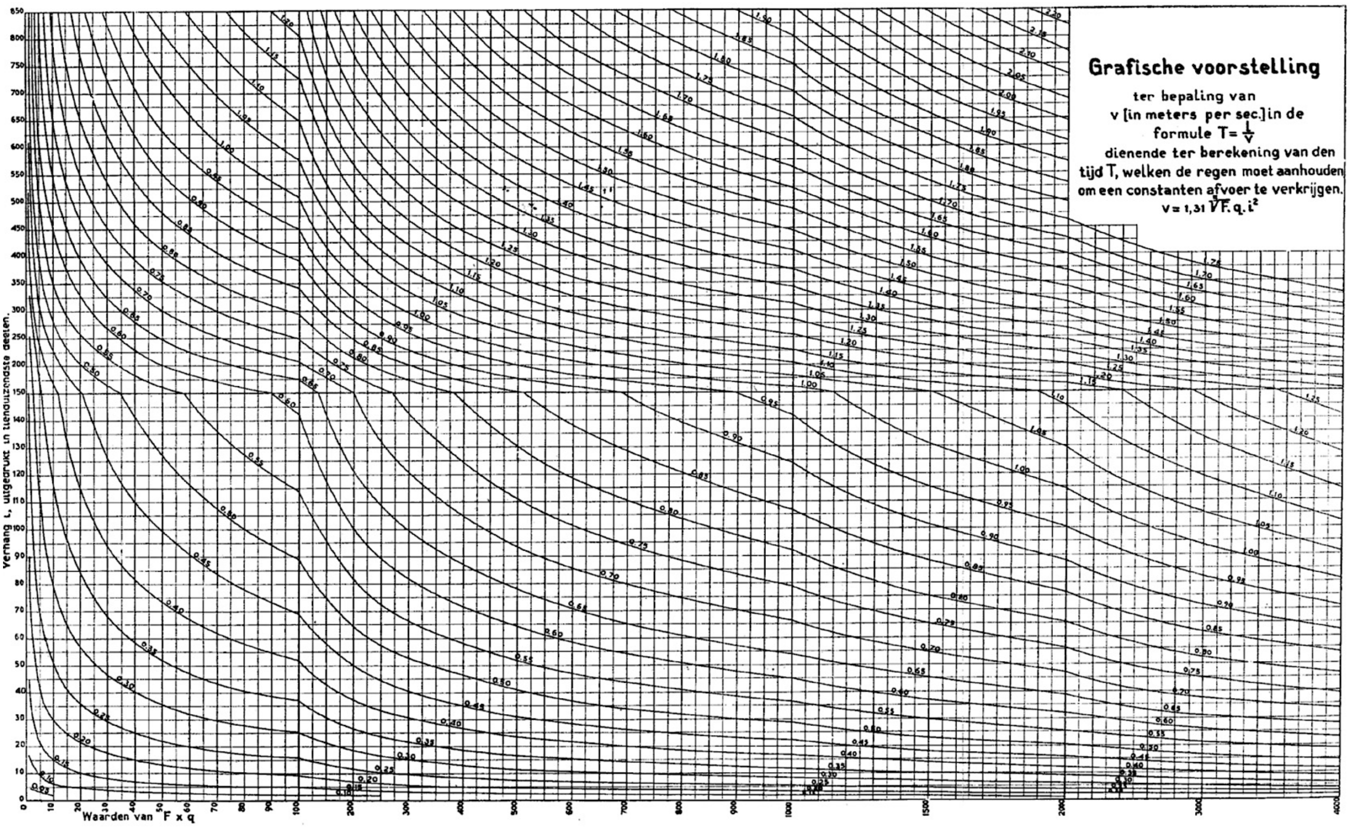

Figure A2. "*Graphical view to determine v in m/s in the formula $T = L/v$, which is used to determine time T needed to reach constant river discharge*" – Graph used for Melchior to derive the velocity component v to calculate the time period of rainfall needed to reach constant peak discharge T (Nijman 1933) – vertical axis showing slope i, horizontal axis showing values for nF, with lines for different values for v (lowest line $v = 0$, with differences of 0.05 per line, highest value 2.20.)

Table A2. Design values for Melchior to correct calculated values for typical discharge per surface unit q with calculated values for the time period of rainfall needed to reach peak discharge T (Nijman, 1933).

T (min)	Percentage to be added	T (min)	Percentage to be added
40	2	1330–1420	18
40–115	3	1420–1510	19
115–190	4	1510–1595	20
190–270	5	1595–1680	21
270–360	6	1680–1770	22
360–450	7	1770–1860	23
450–540	8	1860–1950	24
540–630	9	1950–2035	25
630–720	10	2035–2120	26
720–810	11	2120–2210	27
810–895	12	2210–2295	28
895–980	13	2295–2380	29
980–1070	14	2380–2465	30
1070–1155	15	2465–2550	31
1155–1240	16	2550–2640	32
1240–1330	17	2640–2725	33

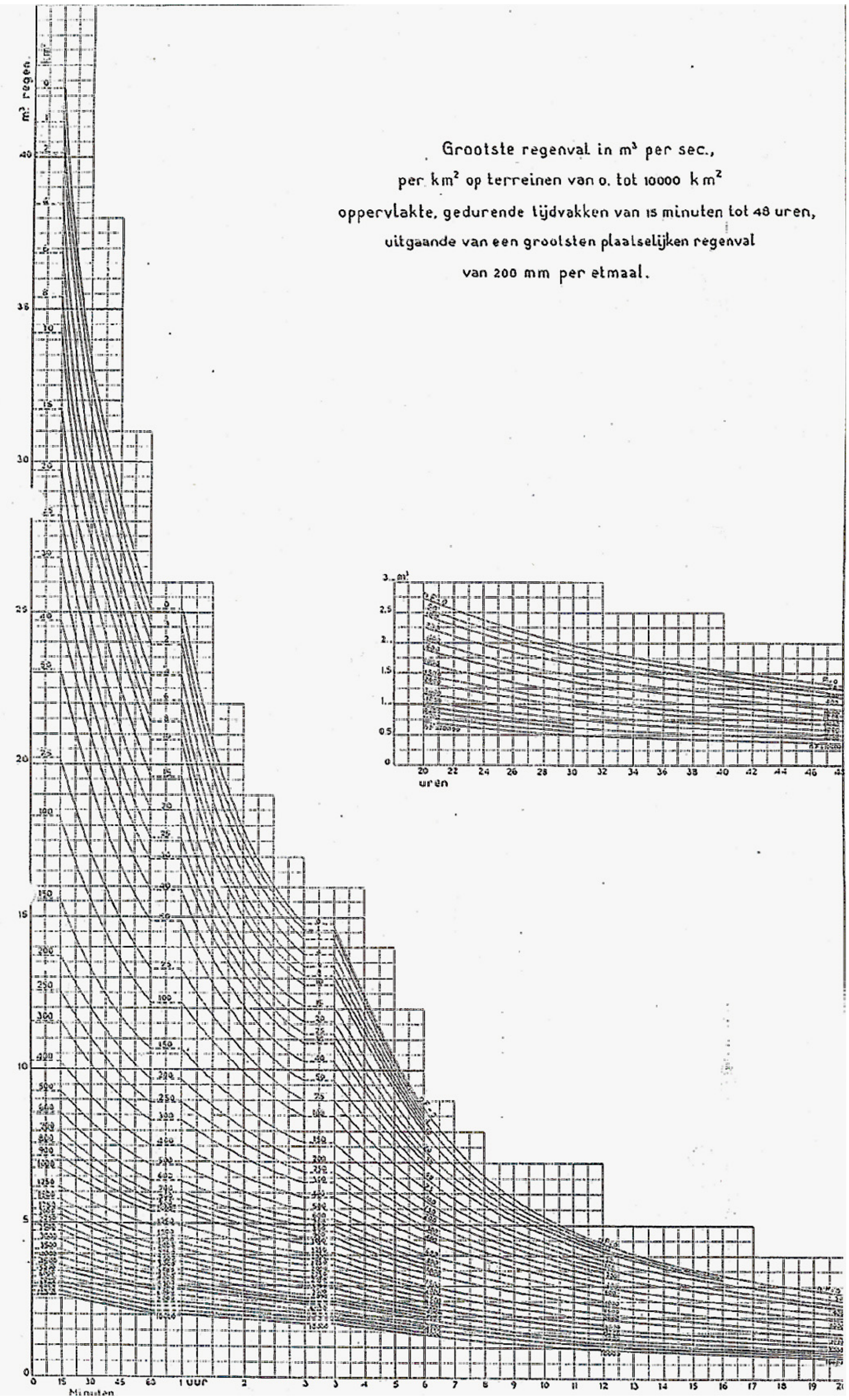

Figure A3. *"Highest rainfall in m^3/s per km^2 on surface areas between 0 and 1000 km^2, for time periods between 15 minutes and 48 hours, taking a highest local rainfall of 200 millimetres per 24 hours"* – Graph used for Melchior to convert surface area of the ellipse nF to typical discharge per surface unit q (Nijman 1933) – vertical axis volume of rainfall in m^3, horizontal axis in hours (with minutes of first hour shown as well), with lines for different surface areas (top line 0 km^2, bottom line 1000 km^2).

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